Response to Reviewer #1

Review of os-2021-96

”Air-sea heat flux during warming season determines the interannual variation of bottom cold water mass in a semi-enclosed bay” by Junying Zhu et al.

Recommendation:

Major revision

Summary:

The authors investigated the interannual variation of a bottom cold water mass (BCWM) formed in the summer in Iyo-Nada, the Seto Inland Sea, based on ship-based hydraulic observations and a three-dimensional hydrodynamic model. The results indicate that the heat transport during the stratification season may affect the interannual variation, in addition to water temperature before the season (so-called pre-conditioning). They also considered that control factors of interannual variations differ depending on the size of BCWMs, through comparison of BCWMs in some regions. These results are important in understanding changes in coastal seas and predicting future changes under climate change. I recommend that the paper be published in Ocean Science after some major revisions. My concerns are listed in *Major comments* below.

Thanks for your careful reading and comment. Following your comments, we have finished a comprehensive revision on the original manuscript. Below is a point-to-point response.

Major comments:

1. As a central result of this paper, Figure 5 shows that the interannual variation of the Iyo-Nada bottom cold water mass (INCWM) depends on both the local water temperature in April (the horizontal axis) and the water temperature at the strait in July (the vertical axis). This means that the INCWM are affected by both the early pre-conditioning and the horizontal heat advection during the stratification season (summer). I think this is the most important result of this paper, but is that okay? If so, it appears to be inconsistent with discussion of Sec. 4.1, which emphasizes sea surface heat

flux as the main factor based on model results. I suggest to reconsider the title of the paper, too.

Thanks for your careful reading. We analyzed the processes influencing the interannual variations of the INCWM in Section 3.3. According to Fig. 5, we found that the influencing processes are not only the early pre-conditioning, but also the vertical and horizontal heat advection during warming season. Since the temperature in April which means pre-conditioning and that at Hayasui Strait in July (which showed the horizontal heat advection) is easier to obtain than the index for vertical heat advection in summer, so we plotted the Figure 6 to show the relationship between the two factors and INCWM intensity. However, the vertical heat transfer is also important which is not easily indicated by observed water temperature in Fig. 6. We modified the description to avoid this misunderstanding in Section 3.3.

"As a summary, the temperature change of INCWM in July on an interannual scale is controlled by three heat transfer processes, i.e., the local retention of bottom low water temperature from early spring, local vertical heat diffusion from May to July and horizontal heat advection originating from Hayasui Strait in July (Fig. 6). Since the water temperatures in April and that at Hayasui Strait in July are easy to obtain from observation. The relationship between them with the INCWM intensity is shown in Fig. 7. A strong INCWM corresponds to a combination of a low local initial water temperature in April (11.0-12.5 ℃) and a low water temperature at 10-50 m deep at station R in July (19.5-20.3 ℃). Conversely, a weak INCWM usually corresponds to a combination of a high local initial water temperature in April (11.7-14.1 ℃) and a high water temperature (19.8-20.9 ℃) in the Hayasui Strait at depths of 10-50 m in July. This provides an intuitive understanding about the INCWM intensity and its relationship with initial water temperature before formation and remote horizontal heat advection in July. However, it is noted to say that local vertical heat transfer during warming seasons is not included in Figure 7."

Global climate change affects coastal seas via regional sea surface forcing. Previous studies had suggested that air-sea heat flux is the key factor for water temperature variation inside the Seto Inland Sea (Tsutsumi and Guo, 2016) and an important factor influencing the variation of other BCWMs (Zhu et al., 2018). Combined with observation results, we discussed the influence of air-sea heat flux to INCWM characteristics using a hydrodynamic model in Section 4.1 and several sensitivity numerical experiments. The Section 4.1 is a further discussion based on Figure 6 and it is consistent with Figure 6.

In this study, we demonstrated the interannual variation of INCWM and its influence process using long-term observation data, and discussed the sensitivity of INCWM to air-sea heat flux changes. According to your suggestion and our deep thinking, we changed the title to "Interannual variation of a bottom cold water mass in the Seto Inland Sea, Japan" in the revised manuscript.

(a) P.9 L. 213-220

Please emphasize that important results were obtained indicating that the interannual variation depends on both.

Thanks and changed as your suggestion. We demonstrated the importance of not only water temperature before INCWM formation, but also the heat transport processes (horizontal and vertical) during warming seasons for interannual variation of INCWM in the last paragraph in Section 3.3.

(b) P.11 L.245 *we conclude that the vertical and horizontal heat transport processes in the warming season, rather than the initial condition preserved from the previous winter, are responsible for interannual variation in the INCWM in July.*

First, the evaluation of the vertical heat flux seems to be inconsistent with the observational results, and so an explanation to address it is needed. Next, Fig. 5 shows that the initial temperature is also important. I do not think the expression "rather than" is grounded.

Thanks for your comment. The Fig.5 has been changed as Fig. 6 in the revised manuscript. First, for influencing process on interannual variation of INCWM, we demonstrated the importance of early pre-conditioning, the vertical heat transport during warming season (from May to July) and horizontal heat advection in July according to observation data (Figure 5). Figure 6 just provides an intuitive understanding about INCWM intensity and initial water temperature before formation and horizontal heat advection in summer. We did not compare the relative importance among the three processes based on observation data.

In the old manuscript, we tried to quantify the contribution of sea surface forcing on interannual variation of INCWM using an index (*cr*). However, *cr* has no clear physical meaning and is not suitable to assess the contribution rate. Therefore, we remove the information about *cr* in the revised manuscript. We just evaluated the sensitivity of INCWM to air-sea heat flux changs.

By comparing sensitivity coefficient q in the vertical and horizontal plane, as well as heat content of INCWM change (Table 2), the conclusion was changed as "*From the three sensitivity numerical experiments, we concluded that INCWM characteristics were more sensitive to air-sea heat flux changes during warming seasons than those in the previous winter*" in the last paragraph in Section 4.1.

(c) P.12 L.281 *we found that the vertical and horizontal heating processes during the warming season, rather than the initial temperature before warming, were the dominant factor for interannual variation in the INCWM.*

Reconsider this part following the above comment (b).

Refer to the answer for the previous question, according to sensitivity numerical experiments, we have changed the sentence as "*INCWM was more sensitive to air-sea heat flux change in summer than that in the previous winter*" in the third paragraph in Section 4.2.

(d) P.14 Table 3

As explained above, I do not think that the "Main factor" of "Iyo-Nada" is only "Air-sea heat flux during stratified seasons".

We reconsidered the influence factor based on the results of sensitivity numerical experiments and changed as "*more sensitive to air-sea heat flux change during warming seasons than that in the previous winter*" in Table 3.

(e) P.17 *Therefore, with respect to interannual variation in the INCWM, the heat transport process during the warming season is more important than the initial temperature after the cooling season.*

As noted above, I do not think that "more important" is well-founded.

As answered above, we changed as "*Sensitivity numerical experiments showed that the air-sea heat flux change during the warming season plays an important role in the interannual variation of the INCWM its sensitivity coefficient is larger than that in the previous winter. This means that the heat transport process during the warming season impacted by air-sea heat flux change might be the priority with respect to interannual variation in the INCWM*" in the first paragraph in Section 5.

2. Temperature distribution of the INCWM should be shown, not only for the average, but at least for a strong-INCWM year and a weak-INCWM year. In July of Fig.2a alone, the reader does not know what kind of interannual change have occured as a whole. It is also necessary to explain that the July analysis is sufficient. (The same result can be obtained for August, right?)

Thanks for your suggestions. We add the temperature distribution of the INCWM in July from 1994 to 2015 in the Supplementary Fig. 3 and characteristics of INCWM in July in Supplementary Table 2. Meanwhile, we add the relevant description about the interannual variation of INCWM in Section 3.1.

In August, the INCWM also exists in the vertical transect (Supplementary Fig. 4) with minimum water temperature ranging 18.52℃ (1996) – 20.75℃ (2014) which is 2℃-3 ℃ higher than that in July. We calculated the average temperature and area surround by an isotherm of 20℃ as Supplementary Fig. 4 shown. The results also showed significant negative correlation between average temperature and area which is consistent with the relationship in July. However, there was no significant correlation for interannual variation of INCWM characteristics between July and August. Because more typhoons pass through Japan in August than in July (http://www.data.jma.go.jp/obd/stats/data/bosai/tornado/stats/monthly.html), we use the INCWM in July to explore the interannual variation of INCWM in this study to avoid the episodic impact of typhoon as far as possible. The information about INCWM in August has added in the second paragraph in Section 3.1.

3. A schematic diagram will help the reader's understanding. I want the figure to include a estuary circulation. It would also be better if the figure could be applied to the discussion of ”cylinder” in Sec. 4.2.

Thanks for your suggestion. We plotted the schematic diagram (below) of seasonal evolution of INCWM from the previous winter to this summer according to Takeoka (2002), Yu et al. (2016) and Yu and Guo (2018) as Fig. 6 in the revised manuscript. In summer, a density-induced gravitational circulation occurs as the bottom water flows from the Hayasui Strait to Iyo-Nada, whereas the surface water flows in the opposite direction. This circulation can be enhanced in July by an abrupt increase in river discharge into the Seto Inland Sea. The figure helps to understand the heat transport process about INCWM.

In Section 4.2, we simplified BCWM as a cylinder as the horizontal scale of BCWM is much larger than vertical scale. However, the vertical scale is enlarged in the schematic diagram for appropriate presentation (Fig. 6). The schematic diagram is not suitable for the discussion of ”cylinder” in Section 4.2. We showed the ”cylinder” in Fig. 8 to present the discussion result in Section 4.2, which means that the size of INCWM is an important factor for investigating interannual variation of BCWMs.

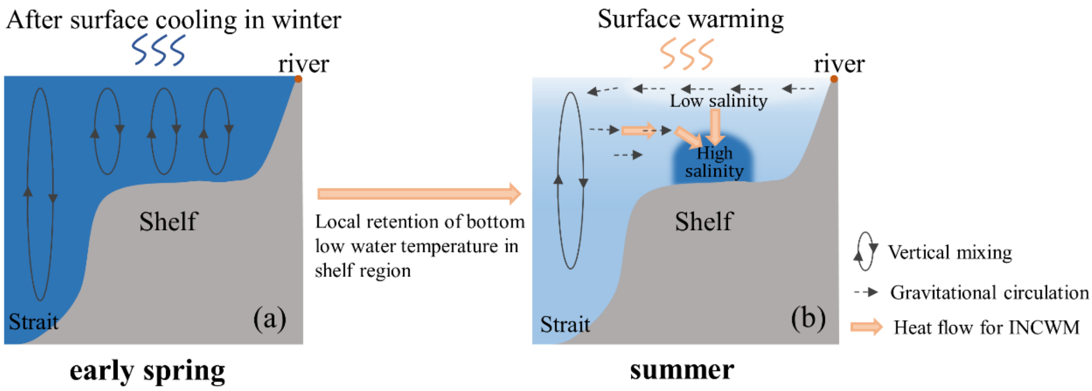

Figure A schematic diagram of seasonal evolution of INCWM from early spring to summer, which is drawn from references Takeoka (2002), Yu et al. (2016) and Yu and Guo (2018). Low water temperature is indicated by dark blue while high water temperature by light blue.

4. Descriptions of the observation and the model specifications are insufficient. Please enrich the explanations.

（a）P.3 Sec. 2.1

It is not enough to explain the observation data only in the first paragraph. Please supplement information on observation methods and accuracy. Are there any documents to refer to?

The observation data was collected from Ehime Prefectural Fishery Research Centers (https://www.pref.ehime.jp/h35115/ehime-suiken.html), we have added relevant description in the first paragraph in Section 2.1 and Supplementary Table 1. The water temperature was measured by ALEC CTD carried by survey vessel “Yoshuu” (よしゅう). The measurement accuracy is 0.001 degree. We add the information in Section 2.1.

（b）P.5 Sec. 2.2

Although written in Zhu et al. (2019), this paper should also outline the model. The following explanations are necessary at least.

i. Model specifications: horizontal resolution, vertical resolution, region, basic classification of model (hydrostatic model? depth-coordinate model?), settings of tides

ii. Experimental settings: initial value, integration period, lateral boundary conditions, sea surface boundary conditions (moved from Sec. 2.3 to Sec. 2.2), rivers

iii. The purpose of using multi-year average (climatological normal) data, instead of actual historical data, for sea surface forcings.

Thanks for your suggestions. We have added the detailed model configuration formation in the first paragraph in Section 2.2.

"Model domain is 130.98°E-135.5°E, 32.8°N-34.8°N covering the entire Seto Inland Sea. The model has a horizontal resolution of around 1 km (1/80° in the zonal direction and 1/120° in the meridional direction), and a vertical resolution of 21 sigma levels. The initial temperature and salinity fields in January were produced by merging the Marine Information Research Center dataset in the SIS region and the model results of Guo et al. (2003). The boundary conditions including de-tided current velocity, temperature, salinity, and surface elevation were obtained from the diagnostic model of Guo et al. (2004). Four major tidal constituents (M2, S2, O1 and K1) were considered and the daily river discharges averaged over 24 years (1993–2016) from the Ministry of Land, Infrastructure and Transport were used in the model. Multi-year averaged daily surface fluxes of momentum, heat and fresh water was used to drive model (Zhu et al., 2019). The daily wind stress was based on hourly averaged results of wind stress, which was calculated by wind velocity from the Grid Point Value of Meso-Scale Model (GPV-MSM) (http:// database.rish.kyoto-u.ac.jp/arch/jmadata/data/gpv/) during 2007–2016 provided by the Japan Meteorological Agency with the resolution of 1/16°×1/20°, adopting the drag coefficient of Large and Pond (1981). The daily shortwave radiation was based on the newly released of Japanese Ocean Flux Data Sets with Use of Remote Sensing Observation (J-OFURO3) (https://j-ofuro.scc.u-tokai.ac.jp/) with a resolution of 1/4°×1/4° and averaged during 2002 to 2013. The daily longwave, sensible heat flux and latent heat flux were calculated and averaged by adopting bulk formula (Gill, 1982) using hourly air temperature, sea surface temperature, relative humidity, cloud cover, and wind velocity from the GPV-MSM (2007–2016). Daily evaporation was obtained by calculating the latent heat flux. The daily precipitation was provided by the GPV-MSM and averaged hourly from 2007 to 2016."

5. It is necessary to improve the structure of the paper to make it easier to understand. I think it is better

that explanation of the analysis method is moved from Sec. 2 to the result sections. Please consider the following modifications.

(a) P.5 The first paragraph

Move it to Sec 3.1。

Thanks and changed as your suggestion.

(b) P.6 Sec. 2.3

Move the explanation of the sensitivity coefficient *q* to Sec. 4.1, since it is used only there. Also, by moving it after defining INCWM, the explanation will be easier to understand. In addition, I could not follow what *cr* means. The authors need to brush up the explanation. I think that the explanation of the experimental cases should be moved to Sec. 2.2.

Thanks for your suggestions. We tried to explore the sensitivity of INCWM to sea surface forcing changes in Sec. 4.1, according to peer reviews and deep thinking, the *cr* was removed in the revised manuscript because it could not account for the contribution of one factor on interannual variation of INCWM.

The sensitivity coefficient *q* was used to quantify the response of INCWM to sea surface forcing changes. As your suggestion, we move the explanation of the sensitivity coefficient *q* to Section 4.1 and move the explanation of the experimental cases to Sec. 2.2.

Minor Comments:

6. P.1 L.14: *The interannual variation in water temperature inside the INCWM showed a negative correlation with the area of the INCWM,*

It is difficult to understand what kind of interannual variations has been observed. Please give a brief explanation using rough numbers, such as temperature and volume in strong-INCWM years and weak-INCWM years.

Response:

Thanks and changed as suggestion. We changed the sentence as "*Surrounded by 18 ℃ isotherm, The observed multi-year average water temperature inside the INCWM was 17.58 ℃ with a standard deviation of 0.27 ℃, while the mean area of INCWM was 5.73×105 m2 with a standard deviation of 4.35×105 m2. Their interannual variation showed a negative correlation with the area of the INCWM that indicates a low temperature corresponds to a big area*".

7. P.5 L.100 *The mean range of change over the entire study period is denoted by the mean value of the absolute value of* ΔX_i

I think that the standard deviation is usually used, when the magnitude of variation over time is investigated. Explain why you use this definition.

Thanks your suggestion. As your suggestion, we have already used the standard deviation to get the intensity of INCWM. Using the standard deviation, we only get one strong INCWM year (2006) and two weak INCWM years (1997 and 2014). The INCWM intensity in other year was not recognized which is not beneficial to analyze characteristic of strong and weak INCWM years in Fig. 5. To widely identify the intensity of INCWM, we used the method described in the paper which have been applied to Yellow Sea Cold Water Mass (Zhu et al., 2018) to get the intensity of INCWM. By this method, the strong INCWM year (2006) and weak INCWM years (1997 and 2014) identified by the standard deviation were also recognized, meanwhile, it recognized the INCWM intensity in other years which is beneficial to analyze characteristic of strong and weak INCWM years in Fig. 7. Therefore, it was better to get the INCWM intensity using this method than the standard deviation.

8. P.7 L.156 *the average water temperature and area inside the 18 C isotherm were calculated.*

Please write the formula for calculating the area-averaged value from the observation data, in order to show the treatment of the area.

Thanks your suggestion. We add the following description of the calculation method in the first paragraph of Section 3.1.

"*When calculating the average temperature and area of INCWM along the vertical across-section, we first interpolated the observed water temperature into a rectangular mesh grids (0.01 ° × 1 m) to get a temperature field, and then calculated the area of grids where temperature less than 18 ℃ and average temperature within these grids. If there was no water temperature less than 18 ℃ in the vertical transection, the observed temperature at the average location of the INCWM (50 m deep at station 3) as the average temperature and the area is set to zero*."

9. P.12 L.266 *Compared with these BCWMs,*

I think the expression "In the same way as in these BCWMs" is better to indicate that the INCWM has the same characteristics as BCWMs in other regions.

Thanks and changed as suggestion.

10. P.12 L.285

Clarify the purpose of the analysis in the rest of this section.

Thanks for your suggestions, we added the sentences "*It is suggested that influence factors for interannual variations of BCWMs vary in different coastal seas though their seasonal cycles and formation processes are similar. This shows the unique response of different shelf seas to climate change. Since BCWMs have important effects on ecosystem and fishery, this finding also provides an insight to understand the different interannual changes of ecosystem and fishery in coastal seas with BCWMs*.

11. P.15 L.335 *As R is much larger than H (at least 1000 times), the influence of* Δm *is supposed to be more important than that of* Δn.

Is it true? The heat flux fluctuation due to horizontal advection, Δn, can be larger by several orders of magnitude than the air-sea heat flux fluctuation, Δm. And, this sentence seems to be inconsistent with the argument that horizontal advection from the strait is more important for interannual variation than the local sea surface heat flux during the stratification season, based on the results of Fig. 4 and Fig. 5.

Kindly, based on Fig. 5, we demonstrated the importance of early pre-conditioning, the vertical heat transport during warming season (from May to July) and horizontal heat advection in July. However, we did not compare the relative importance among the three processes based on observation data. As for Fig. 7, we just showed the relationship between INCWM intensity and local water temperature in April, water temperature of Hayasui Strait in July. We changed the description of Fig. 5 and Fig. 7 to avoid this misunderstanding in the revised manuscript.

Thanks for your comment. For the sentence, Δm is the variation value of air-sea heat flux on an interannual scale, and Δn is the variation in the lateral heat flux on an interannual scale. Since Δn is not easily to be evaluated, this statement is too arbitrary though R is much larger than H (at least 1000 times). We changed this sentence as "*As* Δn *is not easily to be evaluated, we could not evaluate the importance of* $\Delta m \cdot R$ *and* $\Delta n \cdot H$*, though* R *is much larger than H (at least 1000 times)*" in Section 4.2.

12. P.17 L.368 *The interannual variation of the mean water temperature inside the INCWM and that of*

its area show a significant negative correlation.

Explain in detail the interannual variation. (See my comment No.6.)

Thanks for your comment. We have added the description about the interannual variation of INCWM in the Section 5.

"*Observation shows that the INCWM is not significant in 2007 with water temperature higher than 18 ℃. The mean water temperature inside the INCWM was 17.58 ℃ with the lowest temperature 17.04 ℃ (2006) and the highest temperature 18.23 ℃ (2007), while the mean area of INCWM was 5.73×106 m2 with the smallest area 0 m2 (2007) and the largest area 1.46× 106 m2 (2006). The interannual variation of the mean water temperature inside the INCWM and that of its area show a significant negative correlation*"

13. P.17 L.383 *As an extension, we analyzed the control processes on interannual variation of water temperature in the five BCWMs reported in the literatures using a cylinder column to represent their shape.*

This sentence alone is difficult to understand. It is desirable to add a schematic diagram.

Thanks for your suggestion. We added a schematic diagram of seasonal evolution of INCWM in Fig. 6 and "cylinder column" in Fig. 9 to make it clear. we simplified BCWM as a cylinder as the horizontal scale of BCWM is much larger than vertical scale. In Fig. 9, the cylinder at the bottom means the size of BCWM for which the horizontal and vertical are not proportional.

14. P.4 Fig. 2

Add a panel number for each month, such as Fig.2 (a) for January, Fig.2 (b) for April etc.

Thank you and changed as suggestion.

15. P.6 Table 1

Add the CONTROL experiment to the table.

Thank and changed as suggestion.

16. P.7 Fig. 3

The "area" means "vertical cross-section area"? It may be misunderstood like a horizontal area.

Thanks for your suggestion. The "area" means "vertical cross-section area" and we have changed the wording in Fig. 4.

17. P.8 Fig. 4

The example marks at the bottom right of the figure should be changed from an open circle and star to a closed circle and star.

Thank you and changed as suggestion.

18. P.8 Fig. 4

This figure does not plot observation points with the significant difference level of 0.95 or less, right? Since it looks as if there had been no observations, those points should be also indicated (maybe black dots?).

Thanks for your suggestion. We repainted the Fig. 5 and marked correlation coefficients and significant difference levels at all observation depth of each station.

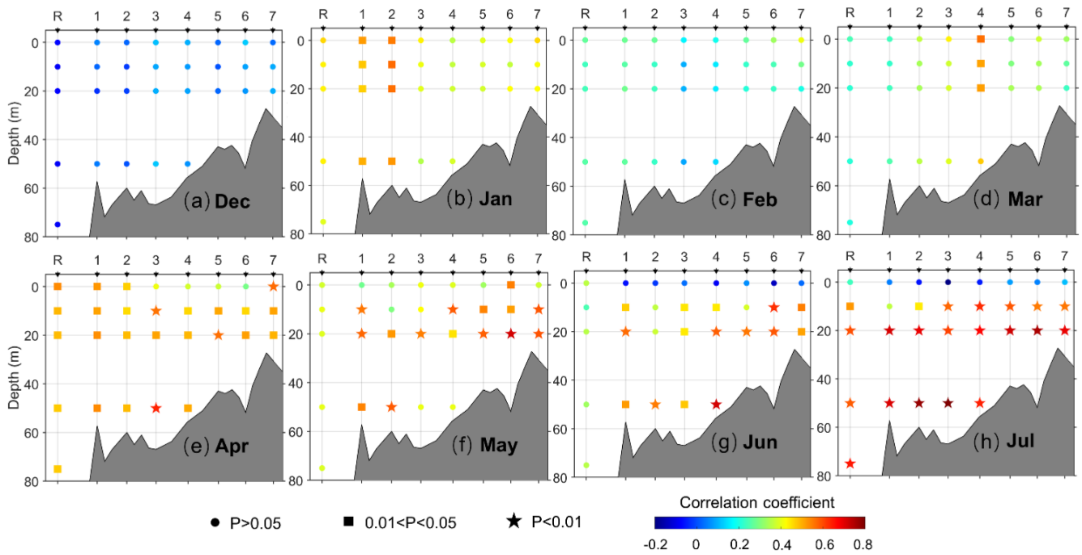

Figure 5: Correlation coefficients for interannual variation of water temperature at each station from previous December to July (a-h) and that of the Iyo-Nada bottom cold water mass (INCWM) mean water temperature in July during 1994-2015. Circles indicate that the significant difference level is less than 0.95, squares indicate a significant difference level is between 0.95 and 0.99, and stars indicate a significant difference level of more than 0.99.