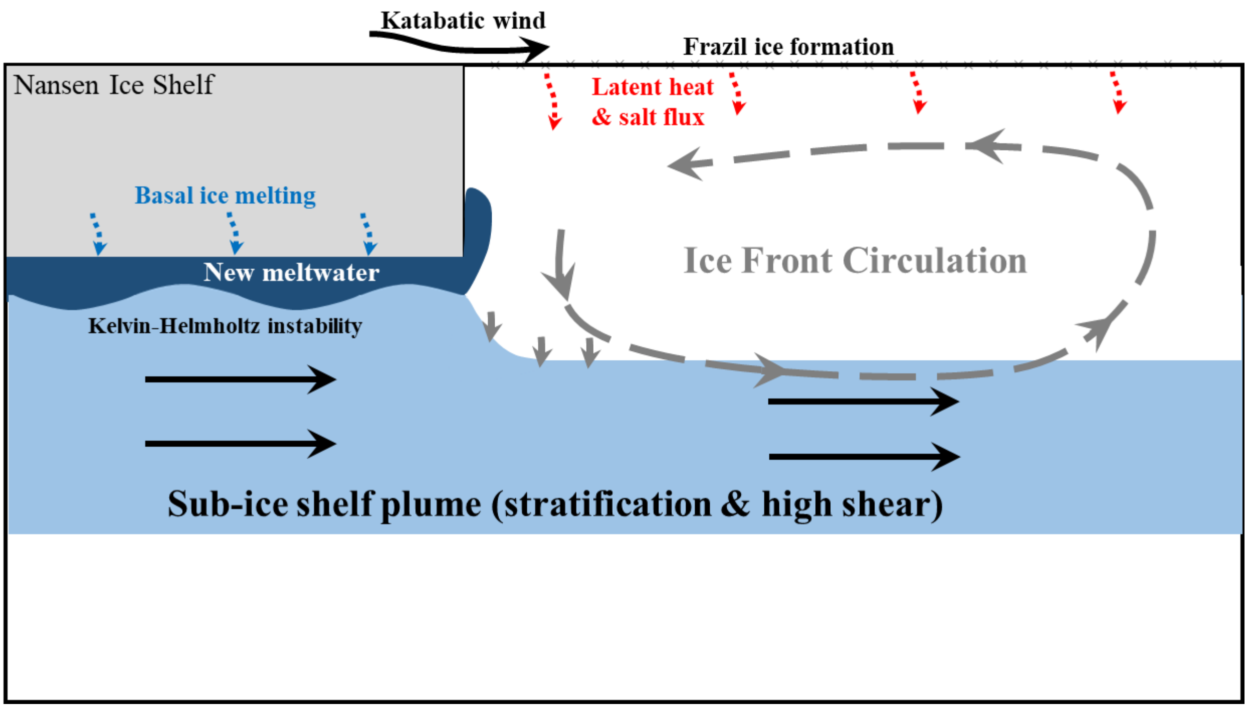
Response to comments

We wish to thank anonymous reviewer for their valuable comments, which will help us to improve our manuscript. We addressed each of the comments in turn below. Our responses are colored by green.

* New simulation summary

We really appreciate the reviewer's valuable comments on the improvement of model validity. We performed a suite of new simulations with proper forcing based on the reviewer's comments and physical oceanography of Nansen ice shelf. Before response to each of the comments, we would like to address major changes and summary of new simulation set-up for model validation with proper forcing based on in-situ observations.



R-Figure 1. Schedamic diagram of physical processes within model domain based on in-situ CTD, LADCP, AWS (in ice breaker Araon) observations. It represents our conclusion inferred from observational and experimental evidences in revised manuscript.

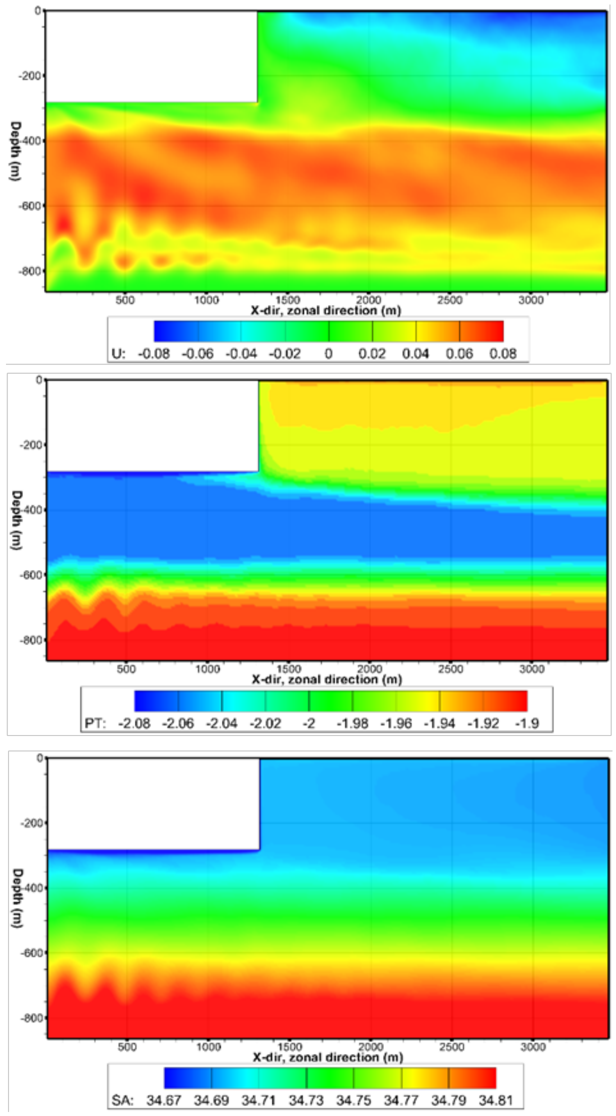
To answer the first comment of reviewer, we describe the physical oceanographic processes and our finding in Nansen ice shelf in late summer using schematic diagram (R-Figure 1)

Through observing negative velocity near sea surface and positive velocity at sub-ice shelf plume in our LADCP observations, we define the "Ice Front Circulation" (In this study, we define this circulation de novo). Shear by momentum of sub-ice shelf plume and salt flux by frazil ice formation (~1 cm day^{-1}, it is determined by sensible heat (164.8W m^{-2}) based on air temperature (–7.76 °C) and wind velocity (16.23 m s^{-1}) obtained by AWS in ice breaker Araon) could trigger this circulation. The relationship between sensible heat and frazil ice production (frazil ice production = 0.1785 x Q_s – 28.048) is referred from Thompson et al. (2020). This circulation pushes the sub-ice shelf plume, making that stratification line is moved to 400 m depth. Beneath the ice shelf, basal ice melting occurs because sub-ice shelf plume has a warmer temperature (–2.06 °C) than local freezing temperature (–2.115 °C) (Note that the freezing temperature was set too high as –1.92 °C in previous simulation. New simulations show not refreezing but melting and it will be described in revised manuscript.). Newly generated meltwater by basal melting is located between ice shelf bottom and stratified sub-ice shelf plume. By density difference between new meltwater and sub-ice shelf plume, shear instability (e.g. Kelvin-Helmholtz instability) occurs at this depth range (from 280 m to 300 m depth).

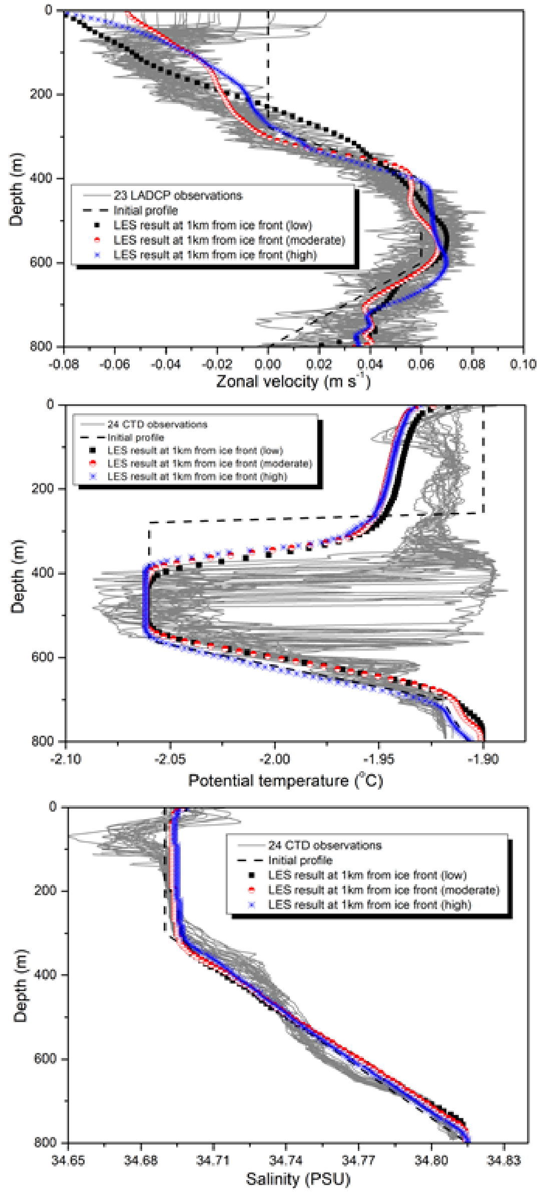
To prove this hypothesis, we set the latent heat and salt fluxes (corresponding to 1 cm day^{-1}) at top boundary and velocity of sub-ice shelf plume (similar with LADCP) at inlet boundary. In temperature between sub-ice shelf plume and ice shelf, –2.06 °C was set. In salinity profile, high stratification was set at 300 m with initial depth (20 m) of new meltwater. In upper region (from 0 to 280 m depth) at the open ocean, 0 m s^{-1} velocity and zero velocity shear at top boundary were set to prove the development of Ice Front Circulation and its trigger mechanism.

To resolve interfacial temperature and salinity by different depths, we used the equation of $\theta_b = \lambda_1 S_b + \lambda_2 + \lambda_3 P$, instead of Eq. (12) $\theta_b = -\lambda S_b$ in previous manuscript.

To investigate the effect of grid size on model performance, we tested the three kinds of grid systems (low case – 216 (16 m) x 216 (16 m) x 108 (8 m), moderate case – 288 (12 m) x 288 (12 m) x 144 (6 m), and high case – 432 (8 m) x 432 (8 m) x 216 (4 m), respectively. In this grid sensitivity study, we conclude that grid resolution in moderate case is enough for resolving this oceanic flow and IOBL.



R-Figure 2. xz plane contours of time averaged variables of velocity (upper), potential temperature (middle) and salinity (lower) in new simulation (moderate case).



R-Figure 3. Vertical profiles of velocity, potential temperature and salinity in new simulation.

Also, we summarized important parameters and constants for basal ice melting at ice shelf bottom and frazil ice formation at sea surface (R-Table 1).

R-Table 1. List of model parameters and constants

λ_1	Freezing temperature salinity coefficient	-0.0573	°C kg g^{-1}
λ_2	Freezing temperature constant	0.0832	°C
λ_3	Freezing temperature depth coefficient	-7.53×10^4	°C m^{-1}
Γ_S	Salt turbulent exchange coefficient (sea surface, ice shelf bottom)	2×10^{-4} [a], 2.6×10^{-4} [b]	-

Γ_θ	Heat turbulent exchange coefficient (sea surface, ice shelf bottom)	5.8×10^{-3} [a], 8×10^{-3} [b]	-
c_w	Specific heat capacity of pure water	3974	$J\ kg^{-1}°C^{-1}$
L_i	Latent heat of fusion	3.35×10^5	$J\ kg^{-1}$
ρ_w	Density of water	1028	$kg\ m^{-3}$
ρ_i	Density of ice	917	$kg\ m^{-3}$
z_0	Surface roughness (sea surface, ice shelf bottom)	0.001, 0.07 [c]	m
-	Ice shelf thickness	280 [d]	m
θ_f	Local freezing temperature (sea surface, ice shelf bottom)	−1.9, −2.115	°C
θ_a	Ambient temperature (sea surface, ice shelf bottom)	−1.9, −2.06	°C
θ_b	Interfacial temperature (sea surface, ice shelf bottom)	−1.885, −2.092	°C
Sa_a	Ambient salinity (sea surface & ice shelf bottom)	34.69	psu
Sa_b	Interfacial salinity (sea surface, ice shelf bottom)	34.864, 34.286	psu
k_θ	molecular diffusivities of heat	1.3×10^{-7}	$m^2\ s^{-1}$
k_S	molecular diffusivities of salt	7.2×10^{-10}	$m^2\ s^{-1}$

a - Heorton et al. (2017)

b - based on friction velocity (0.145 m s^{-1}) and thermal driving in new simulation (refer to Vreugdenhil and Taylor (2019))

c - high drag coefficient (C_d = 0.01) of cold water cavity in Gwyther et al. (2015)

d - Stevens et al. (2017)

Anonymous Referee #1

- General comments

There are important gaps in our knowledge of sub-ice shelf ocean dynamics, particularly in the freezing regime. Na et al. have set their sights high in this study, but the manuscript as submitted does not provide sufficient evidence of model validity. In fact, there are several theoretical reasons to believe that the dynamics are not adequately represented in the model. Their argument for validity chiefly rests on the match between simulated temperature and salinity profiles and observations. Since the model has observations as initial conditions and an inflow boundary condition, it is unclear how far from observations the simulations could evolve. Furthermore, their presentation of the results and discussion of the turbulent dynamics must be more thorough to substantiate many of their scientific conclusions. This study could be publishable after an expanded discussion of model limitations and scaled-back claims to model realism, more elaboration of simulation results, and an expanded discussion of existing literature on frazil ice dynamics.

- As the reviewer mentioned, this study is new approach about sub-ice shelf ocean dynamics with sub-ice shelf plume which was observed in 2016/17 in-situ shipboard using 3D large eddy simulation with thermal and salty fluxes based on Monin-Obukhov similarity. To reply to the reviewer's comment, we conducted new simulations of the IOBL and ocean dynamics under other conditions (profiles) to prove the validity of this model. In response to comments, we made some efforts to explain the validation issue and several limitations.

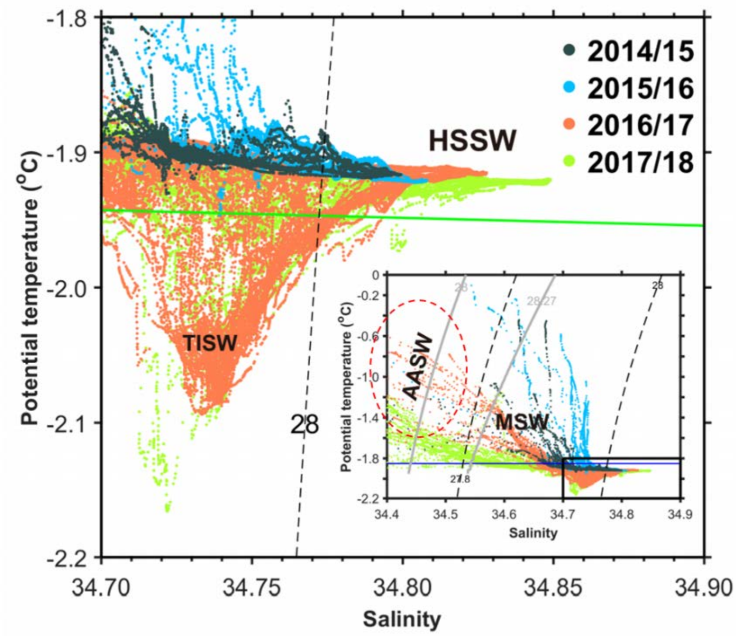
- Specific comments

The connection to existing literature is inadequate. The readers need to know the physical oceanographic context for the region to assess the strengths and shortcomings of the model and the model setup. What is driving ocean circulation in reality and in the model? We also need to know what observational estimates exist of melting and freezing rates of the Nansen Ice Shelf to determine whether the simulated freezing rates are realistic (Is Mode 3 melting present at Nansen Ice Shelf?). Regarding the result that refreezing rates are high at the ice shelf front, is there any observational basis for this pattern or are you proposing it de novo?

– As the reviewer mentioned, Mode 3 (Antarctic Surface Water, AASW) was observed in Nansen ice shelf (red circle in R-Figure 4). However, the Modified Surface Water (MSW) and sub-ice shelf plume was mainly observed in our 24 CTD observations in late summer season. Therefore, driving forces of ocean circulation in our simulation are sub-ice shelf plume (generated by Mode 1) and salt flux at top boundary in the summer season. We will add and re-organize the literature survey for physical oceanography near Nansen ice shelf in revised manuscript.

– To describe the sub-ice shelf plume, we set prescribed-profiles for velocity, temperature and salinity as the inflow, because sub-ice shelf plume is generated at outside of simulation domain. Also, non-cyclic boundary condition (Dirichlet & extrapolation boundary conditions) was used for inflow and outflow boundary owing to spatial heterogeneous due to the presence of the ice shelf. These set-up of our model has the advantage of being able to resolve the target phenomena (e.g. IOBL flow, sub-ice shelf plume dynamics and ice front circulation) under this environment. We will explain this in methodology section in revised manuscript.

– Limitations and shortcomings are absence of the slope of ice shelf and temporal variability of sub-ice shelf plume because we only observe time-averaged features without the slope of ice shelf. This contents will be discussed in discussion section in revised manuscript.



R-Figure 4. T-S diagram (Yoon et al. (2020))

Please provide more context for the observations that are used to initialize the model. There should be a brief presentation of the water masses that are present in the water column and their flow orientation (only zonal velocities are presented). The location of the observations should be shown on the study area figure, and text should indicate their distance from the ice shelf front and the time span over which these observations were collected. It is unclear whether these observations were presented in Yoon et al. (2020) or whether they are published here for the first time. Furthermore, the apparent bimodal temperature distribution at ~500 m depth also needs to be explained so that it's clear why you try to match the low temperature cases.

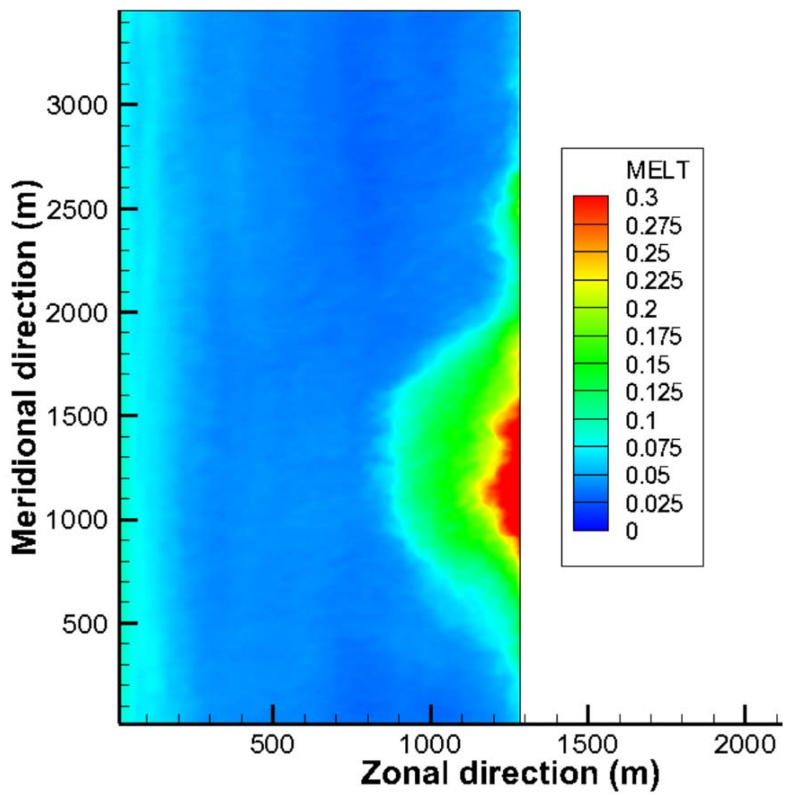
– As the reviewer mentioned, the explanation of observation was insufficient. With schematic diagram of R-Figure 1, we will explain the observation information in detail in methodology section. In new simulation, we used the average value of temperature (–2.06 °C) of apparent bimodal temperature distribution to examine the averaged feature of sub-ice shelf plume. Since this temperature determines the thermal driving at ice surface, we could consider various temperatures of sub-ice shelf plume in future study.

I have philosophical concerns about the manner in which the authors validate the model. Authors argue that the model is valid because the LES results match the observations, but the model is initialized to observations and has inflow that roughly matches the observations. Therefore, the argument seems to be that the model does not drift too far from observations, which may be too weak an argument for model validity. It is also unclear to me where in the LES domain you are evaluating the agreement with observations. There should be a more thorough discussion of model limitations and a discussion of their possible impact on simulation results. There should be an explicit argument addressing whether your LES model can capture freezing dynamics in the absence of frazil ice dynamics. Frazil ice dynamics significantly influence IOBL evolution as documented in previous literature, which also should be cited (including the work of Galton-Fenzi). The lack of ice shelf slope should also be discussed. Furthermore, the parameterization of heat, salt and momentum fluxes at the ice base were developed for the ice melting case by McPhee et al. 1987. The applicability of this parameterization as well as the gamma_T, gamma_S exchange coefficients to the freezing case needs to be discussed.

– To prove the validity of this model, we made some efforts in set-up of initial and boundary conditions. In new simulation, model was validated under complex environments (new meltwater, sub-ice shelf plume and frazil ice formation), in terms of driving ocean circulation, its scale and quantities & trend of variables (velocity, PT and Sa). Differ to the previous simulation, we considered ice melting dynamics beneath ice shelf in new simulation. In latent heat and salt fluxes at sea surface, we considered only total heat content and salt quantity by frazil ice formation (1 cm day^{-1}) without the frazil ice dynamics. Also, we imposed gamma_T, gamma_S based on high-resolution LES study of Vreugdenhil and Taylor (2019) and sea ice study of Heorton et al. (2017). These parameters and absence of frazil ice dynamics will be discussed in discussion section in revised manuscript.

How do you know that the strong refreezing anomaly at the ice front is not a numerical artifact related to the front geometry?

– In new simulation, similar trend (heterogeneous pattern) of melt rate was observed near this region because upwelling of new meltwater and entrainment of outer MSW (from the open ocean), as shown in R-Figure 5. We conclude that there is no numerical artifact because we have checked that momentum flux layer of Monin-Obukhov similarity is established well at node points near the edge of ice front.



R-Figure 5. Melt rate (m yr-1) distribution of new simulation

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What physically determines the location of the transition from the inner to the outer region in terms of refreezing rate? How do you know that this transition isn't just characterized by the development of turbulence along-flow from a less-turbulent inflow? Is there any observational evidence for these trends in refreezing rates, either at this ice shelf or any ice shelf?

– Because we imposed the fully developed inflow of sub-ice shelf plume (based on in-situ LADCP observation profile), the region of turbulent development is relatively small (~ 300 m). In result analysis of revised manuscript, we will exclude the region of turbulence development only to observe the fully developed features.

Line 13: "In particular, it is evident that, when the refreezing effect is considered, the IOBL flow can be more realistically resolved, especially upward advection from the sub-ice shelf plume and the ice front eddy." You don't show that the entrainment and eddying in the freezing case are more realistic, if by realistic you mean closer to observations.

– In new simulation, we observed the development of ice front circulation under environments with meltwater production and salt flux based on in-situ observation. Therefore, we conclude that this simulated oceanic flow is realistic, representing the physical oceanographic processes in

Nansen ice shelf.

Lines 30-45: The modes of ice shelf melting and the classification of warm and cold water cavities should be presented in the context of your study. This paragraph feels too general and unfocussed.

- As the reviewer mentioned, we will include the modes of ice melting, the classification of warm and cold water cavities and Nansen ice shelf characteristics in introduction section in revised manuscript.

Line 41: This sentence should state that the basal melt rate of ice shelves is determined by the rate of BOTH heat and salt exchange, as salt exchange plays a key role in the dissolving regime characteristic of most ice shelf settings.

- We will amend this sentence, including the importance of dissolving regime and salt exchange.

Line 76: "we were able to account for refreezing patterns, detailed flow structures including turbulent characteristics, fluxes and the relationship between refreezing and entrainment of supercooled water from sub-ice shelf plume within the IOBL." This makes it sound as if all of those properties were observed, when in fact you don't present observations that can be linked with those characteristics.

- As the reviewer mentioned, this sentence was not clear. We will amend this sentence, emphasizing that those characteristics were obtained from validated simulation results.

Line 134: I might have missed it but I can't find the value of z_0.

- In R-Table 1, we list-up z_0 values and its reference.

Line 136: It is unclear how the no-refreezing case is configured. Are both heat and salt fluxes set to zero at the top boundary?

- In revised manuscript, we will exclude the no-refreezing case (case without heat and salt fluxes).

Line 145: Argue for the appropriateness of setting a CTD profile that was observed in the open ocean as inflow conditions under the ice shelf.

- Because sub-ice shelf plume is generated from ice melting near grounding line, we cannot resolve this in our simulation domain. Therefore, we have to use the prescribed profiles based on observations. In new simulation, we set the inflow conditions using observation under the assumption that momentum, temperature, salinity of sub-ice shelf plume in the open ocean is similar with those beneath ice shelf. We will explain this assumption and appropriateness in methodology section in revised manuscript.

Line 149: Please specify how the radiation boundary condition is implemented.

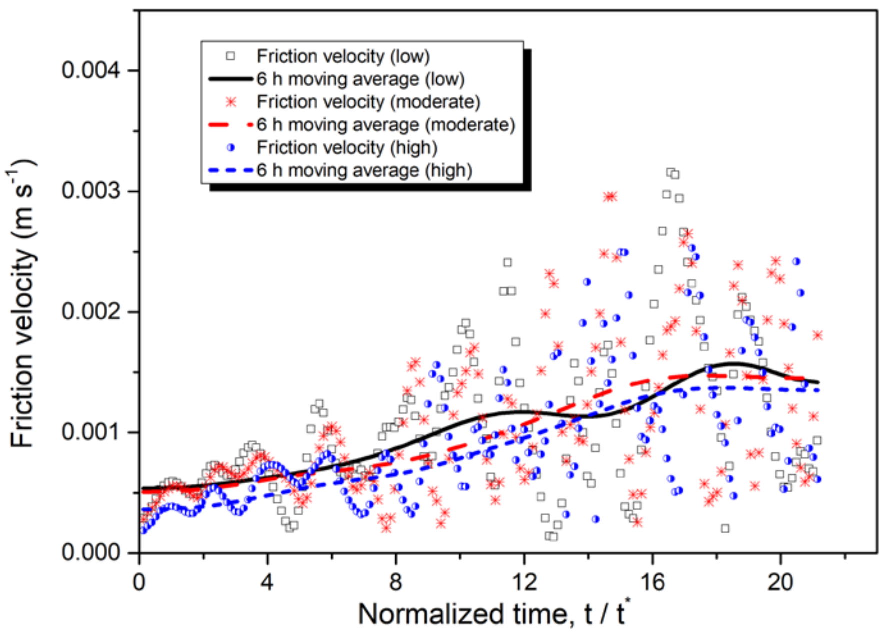
- Radiation boundary condition at outlet boundary is extrapolation boundary condition (gradient of variables are zero) that outlet boundary does not affect the oceanic flow. We will explain this in methodology section in revised manuscript.

Line 150: Further explanation is needed to address how Dirichlet conditions at top boundary are appropriate even under the ice shelf and what they represent in the open ocean. Is this consistent with observed winds?

- Through the AWS observation in Araon, observed wind direction was opposite to upper current direction (negative zonal velocity). It represents that upper current was not developed by winds. Therefore, we set the Dirichlet condition ($v = 0$) at top boundary to exclude the wind effect, because wind effect is out of scope.

Line 153: With what metric is quasi-steady state evaluated?

- We plotted time series of the friction velocity near ice shelf bottom to examine the time convergence. As shown in R-figure 6, it is observed that friction velocity is converged after 17 t^*. Through this feature, we evaluate the quasi-steady state in simulation result.



R-Figure 6. Time series of friction velocity in new simulations with different grid resolutions.

Results: Explain in the refreezing case to what degree the increase in boundary layer temperature is due to the release of latent heat and differences in entrainment.

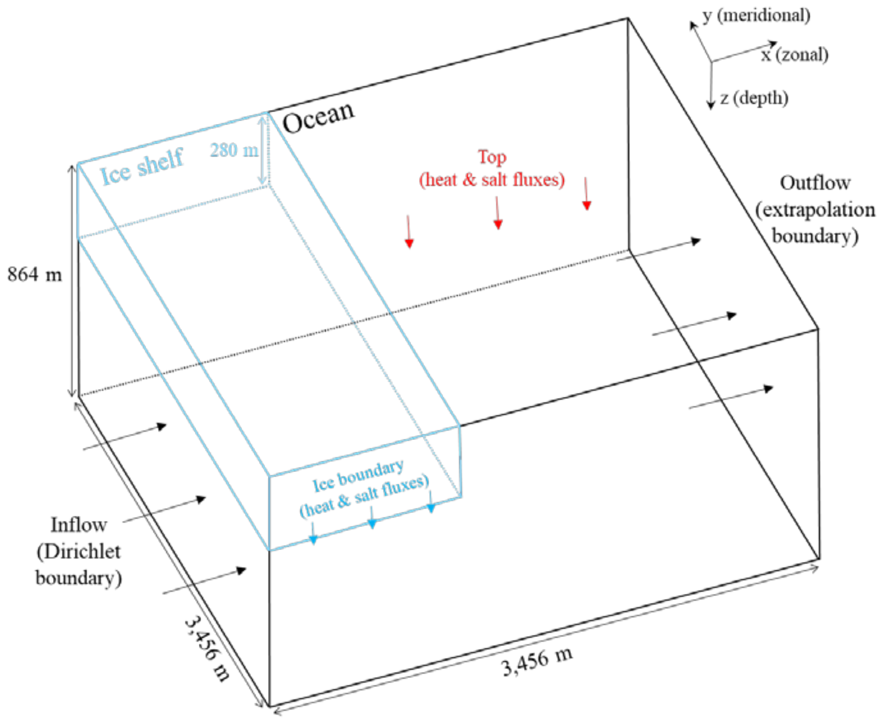
- In new simulation, we did not consider the release of latent heat at ice shelf bottom. Instead of this, we will discuss the specific degree of changes by ice melting at ice shelf bottom and frazil ice formation at sea surface.

Line 178: "This difference is induced by high momentum exchange by refreezing and its brine rejection." This statement is unclear. Is the high momentum flux related to the destruction of stratification by brine release?

- In new simulation, we did not consider the release of latent heat at ice shelf bottom. This statement will be removed in revised manuscript.

The horizontal velocity orientation throughout the text is unclear. Are zonal velocities aligned with the x-axis of the simulation domain? In some places in the text the zonal velocity but not the meridional velocity is presented.

- As shown in R-Figure 7, we will provide information for directions in revised manuscript.



R-Figure 7. Simulation domain and boundary conditions

Line 185: "negative mean velocity": the velocity vector orientation is unclear.

- We will provide information for directions in revised manuscript.

Line 215: "stream-wise zonal velocity": the velocity vector orientation is unclear.

- We will provide information for directions in revised manuscript.

Line 186: The description of the forces responsible for the ice front eddy are unclear. Can you also describe the eddy structure more clearly? Is it a singular overturning cell spanning the length of the ice front?

- In new simulation, the overturning cell near ice front was not observed. So, we will remove these contents for the ice front eddy in revised manuscript.

Line 189: Are you saying here that convection due to brine rejection inhibits entrainment? It is unclear why this would be the case.

- In new simulation, the entrainment will be modulated by Kelvin-Helmholtz instability. We will add the part for this coherent structure of Kelvin-Helmholtz instability based on linear stability analysis and its impact on the entrainment. (Na et al., 2014)

Line 194: "upward advection from sub-ice shelf plume" is unclear. Are you talking about entrainment due to turbulence or advection by the mean flow?

- In previous results, we talked about entrainment due to turbulence (heat advection by turbulent mixing). In new simulation results, we also consider entrainment due to turbulence generated by Kelvin-Helmholtz instability.

Line 195: "stratification is more dominant than flow shear" You haven't made a strong case for this in Results. Perhaps you could move this statement to the discussion and expand on it there.

- In new simulation, flow shear was dominant than stratification within ice ocean boundary layer with shear instability. We will discuss this and expand on it in discussion section in revised manuscript.

Line 200: "upward flow advection" again, is this mean flow or turbulence?

- In this part in previous simulation, we used "upward flow advection" as mean flow (upward moving of sub-ice shelf plume). In revised manuscript, we will remove this.

Line 200: "Since there is no downward force due to brine rejection, the upper region of the sub-ice shelf plume expanded to the upward direction immediately after it passed the ice front." It's unclear what you determine the driving mechanism to be. Is it that changes in stratification determine the sub-ice shelf plume extent or changes in the degree of mixing between water masses or something else?

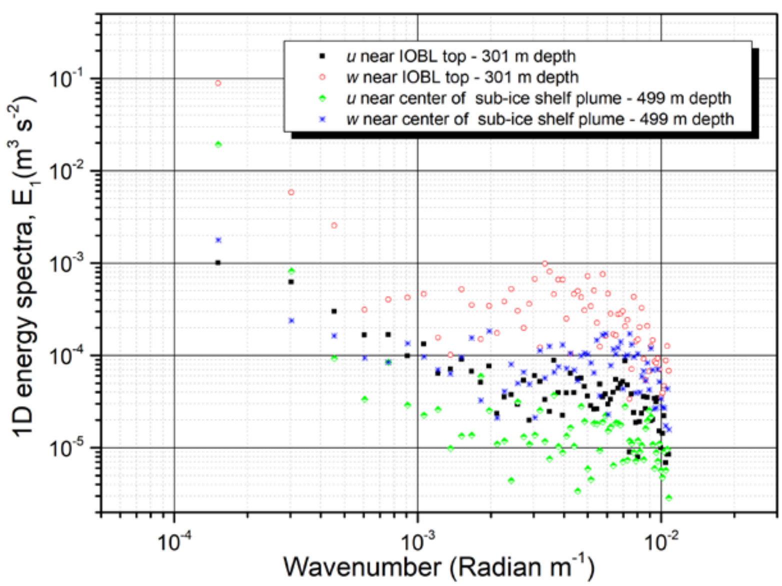
- In new simulation, dynamics and physics were different with previous simulation. So, we will remove this sentence.

Results: The relationship between refreezing and entrainment of supercooled water at the ice shelf front is unclear in the manuscript. How can we tell that the higher rates of refreezing at the ice shelf front are due to entrainment as opposed to reversed flow of cooler water from the open ocean below the ice front?

- In new simulation, it was observed that reversed flow of warmer water from open ocean caused ice melting (R-Rigure 5). We will perform the comparison between vertical heat entrainment and horizontal heat advection to tell the cause of high melting, via integral of heat flux.

Figure 5. Show the inertial subrange in wavenumber space. You mention that the low wavenumber values don't fit the -5/3 slope but aren't these wavenumbers outside the inertial subrange? Why are these spectra so noisy? Could this indicate insufficient spatial or temporal averaging? You don't specify these details in your description of the methodology. It's also unclear why there are several curves for each case and depth. Furthermore, why are the spectra evaluated in 1-d?

- As the reviewer mentioned, energy spectra in low wavenumbers is outside the inertial subrange. When we obtain this spectra plot, we consider velocity fluctuation of spanwise direction (homogeneous by cyclic boundary condition) at specific depth and specific zonal (streamwise) location, because energy spectra calculation have to be performed under the assumption for homogeneous turbulence. in previous simulation, insufficient spatial averaging caused noisy feature. In new simulation, we will plot the energy spectra of *u*, *w* velocity as shown in R-Figure 8.



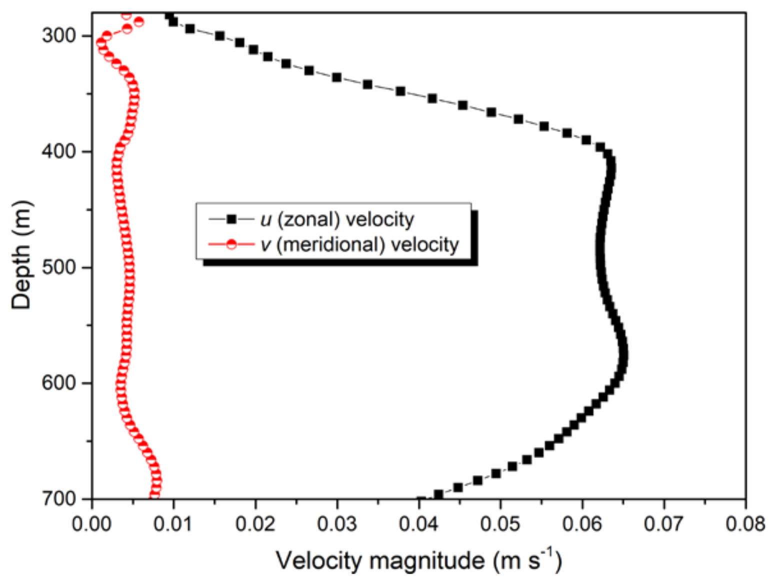
R-Figure 8. 1D Energy spectra in new simulation. These plots are obtained at 600 m zonal distance (ice shelf center).

Figure 7, 8. There doesn't appear to be a relationship between heat flux at -281 m and refreezing rate. Can you explain why this is the case?

- As the reviewer mentioned, heat flux at -281 m was not related with refreezing pattern (melting pattern in new simulation). Because melting pattern is related with temperature, integral of local heat flux near ice shelf will be related with melting pattern. We will re-plot this figure, including relationship between the melting pattern and integral of heat flux.

Lines 215-231: You address differences in velocity magnitude but not orientation.

- To orientation of oceanic flow, we will add vertical profiles of velocities (x, y directions) in revised manuscript. (R-Figure 9)



R-Figure 9. Vertical profiles of velocities beneath the ice shelf.

Line 230: This caveat should be explored more deeply in the discussion.

- In revised manuscript, this part will be moved to discussion section.

Line 234: “it is shown that the LES model adequately resolves the oceanic flow beneath the ice shelf with the proper refreezing effect.” The analysis presented in Section 3.1 does not demonstrate this. You don’t show evidence for sufficient resolution (e.g., a comparison of resolved vs. subgrid energy) or the proper refreezing effect (e.g., a combination of the right theory and match to observations).

- In new simulation, we will discuss the model validity with proper melting effect and latent heat and salt by frazil ice formation with our hypothesis.

Line 240: Needs further discussion in text to explain why vertical velocity is not zero given boundary conditions.

- We will discuss this based on Monin-Obukhov similarity at ice surface in revised manuscript.

Line 257: “strong velocity gradient” in what direction?

- It was vertical gradient.

Line 264: the definition of IOBL should come at the first mention of IOBL in the Results or Methods.

- We will move the IOBL definition to the first mention of IOBL in the results section.

Figure 11: Is IOBL depth the same for both regions? Inset: Is the arrow for the inset meant to correspond to a certain depth? Is sigma the same for both runs? Are there multiple PDFs for each region overlain, because I was expecting to see a single curve for each region as opposed to the scattered points?

In previous simulation, IOBL depth between inner and outer regions was slightly different (inner: 438 m, outer: 447 m).

Line 292: “This water plume refreezes. . .” this statement is only true for some ice shelves.

- Reviewer’s comments is correct. We will amend this sentence.

Line 304: “we used the LES model to expand the one-dimensional observation profile in oceanic region to the three-dimensional flow-field in oceanic region and the sub-ice shelf region.” This statement is imprecise and possibly misleading. It would be more accurate to say that you used the observational profile as initial and boundary conditions and then investigated spatial and temporal variability arising from brine rejection and mixing.

- It will be corrected as the reviewer mentioned.

Line 306: “We assumed that the LES results for the sub-ice shelf region are validated if the LES results for the oceanic region are validated.” See validation comment above.

- Based on new simulation and its validation, we will suggest this statement in revised manuscript.

Line 307: “Via an evaluation of the refreezing effect” It’s not clear what this evaluation consists of and how it supports the validity of the model.

- Based on new simulation and its validation, this part will be changed to “via an evaluation of the melting effect” in revised manuscript.

Line 314: You haven’t provided much explanation of the causes of heterogeneous freezing rates and what controls the scale of turbulence features.

- Based on new simulation, we will discuss this with Kelvin-Helmholtz instability.

Line 315: what is the scale of the ice front eddy and what controls it?

- In new simulation, reversed flow and ice front eddy were not observed.

Line 316: what determines the IOBL depth and does it match the observations?

- We determined the IOBL depth as the depth at 1% of heat flux at ice shelf bottom. We will discuss this in discussion section in revised manuscript.

Line 319: “this study can be improved by comparing LES results with observations and its feedback” What do you mean by “its feedback”?

- “Its feedback” meant the modification of constants or model parameters by the comparison between LES result and in-situ observation. We will rephrase this sentence in revised manuscript.

Line 321: “If a database for flow physics in various parameters is completed” I can see what you’re getting at here, but the wording here is awkward and it’s unclear what you mean by “a database for flow physics.

- In this sentence, database meant the model parameters (e.g. turbulent exchange coefficients) according to various flow environments. We will rephrase this sentence to clarify original meaning.

Line 328: “convergence trend in temporal variance” of what quantity?

- When we mentioned the temporal variance, we examined time series of the friction velocity.

- Technical comments

Make it clear in the introduction why you use the term “refreezing” as opposed to “freezing” There are a few places in the text where you say that water melts, but I think you mean to say that the water mass has a contribution of meltwater from the ice shelf.

- Because there is no refreezing beneath ice shelf in new simulation, we will not use the “refreezing” in introduction section. Text for water mass will be modified as the reviewer mentioned.

Specify which version of PALM you are using.

- We will add the version of PALM (version 6, r4536) at the first mention of PALM in methodology section in revised manuscript.

Line 17: “high shear impact”?

- We will amend this to high velocity shear in revised manuscript.

Line 46, 184: “the shear impact” is confusing if what you mean is more similar to “the direct impact” and does not relate to velocity shear.

- We will amend this to the velocity shear in revised manuscript.

Line 107: Sub-grid parameterizations need a citation.

- This part was referred to PALM description of Maronga et al. (2015). We will add the citation.

Line 181: include a citation for the original definition of the swirling strength criterion

- We will add the reference for the fundamental definition of swirling strength criterion.

Line 182: “Due to” to “At its”

- It will be corrected as the reviewer mentioned.

Line 182: “apart from the ice” to “below the ice”

- It will be corrected as the reviewer mentioned.

Line 206: “with few dissipations” to “with little dissipation”

- It will be corrected as the reviewer mentioned.

Line 235: “explores” to “explore”

- It will be corrected as the reviewer mentioned.

Line 274: “to IOBL the flow”

- It will be corrected as the reviewer mentioned.

Line 277: reference for the flatness factor

- We will add the reference for the flatness factor.

Line 281: strange to say that the vertical velocity fluctuations “have” 3 sigma.

- We will amend this sentence to “scale of velocity fluctuations is corresponding to 3 sigma”.

Line 302: “the numerical approach including the LES” is confusing. Do you just mean LES on its own?

- Yes. We just meant LES. We will amend this in revised manuscript.

In all figures, specify whether results are derived from simulation or observations or both.

- We will specify this in all figures and its captions.

Figure 1: a. Unclear what blue shading designates. Add “sea” to Ross, Amundsen, Weddell, Bellingshausen labels. b. Show ice shelf boundaries and label sea ice areas. c. label ice shelf length dimension.

- a. We will add the “sea” to Antarctica map. b. we will add grounding line and sea ice area in satellite pictures. c. we will add ice shelf length dimension.

Figure 6. b. Show local freezing point, especially given that you claim supercooled water entrainment.

- We will show the local freezing temperature in vertical profile of temperature.

Figure 9. I can't tell the sign of vertical velocity without a reference zero line.

- We will add reference zero line at this figure.

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