Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality.

1st Feb 21

Dear Dr Hirano,

Once again, please allow me to apologise most sincerely for the long delay with sending a decision on your manuscript titled "Poleward eddy-induced warm water transport across a shelf break off Totten Ice Shelf, East Antarctica". It has now been seen by two reviewers, and I include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. In particular, please address the requests by both reviewers to provide a more quantitative assessment of poleward heat fluxes and the resulting melt rates. Please highlight all changes in the manuscript text file.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter) and the completed checklist:
[link redacted]
** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We understand that due to the current global situation, the time required for revision may be longer than usual. We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning. Of course, if you are unable to estimate, we are happy to accommodate necessary extensions nevertheless.

Please do not hesitate to contact me if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Heike Langenberg, PhD

Chief Editor
Communications Earth and Environment

On Twitter: @CommsEarth

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

Editorial Policy: Policy requirements

Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:
Communications Earth & Environment formatting checklist

and also in our style and formatting guide Communications Earth & Environment formatting guide .

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- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

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Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #2 (Remarks to the Author):

Review of "Poleward eddy-induced warm water transport across a shelf break off Totten Ice Shelf, East Antarctica" by Hirano et. al.

This work presents a detailed description of the characteristic mesoscale stratification and circulation over the continental slope off Sabrina Coast, East Antarctica. A thorough analysis of closely-spaced CTD stations across and along the slope provides robust evidence of a persistent zonal train of large (O ~100-250 km) cyclonic "eddies" located between the shelf break and the southern boundary of the Antarctic Circumpolar Current (ACC). Along the eastern limbs of these subpolar cyclones Lower Circumpolar Deep Water (UCDW) drawn from the ACC is brought to the Antarctic Slope Current (ASC), where its extreme properties are attenuated more rapidly to produce Modified CDW (mCDW). The corresponding northward return flows of mCDW (below sill depths) are observed at the eddies western limbs. The authors correctly point out that mCDW remnants observed farther inshore, below sill depths, must result from complex sub-mesoscale interactions between eddies and topographic irregularities along the shelf break.

I find this work acceptable for publication in Communications Earth & Environment. The following comments are mostly suggestions and clarifications that might assist the authors while preparing the final version of this publication.

Title: I would reword "Poleward ... across a shelf break...", since the description is more of the cross-slope fate of warm CDW within multiple small and persistent subpolar cyclones.

I believe this work deals with warm waters being transported cyclonically in the study area, but I would argue that there is no discussion of how much heat is transported across the slope, i.e. what is the net poleward heat transport?

Eddy poleward oceanic heat transport across the ACC is often associated to anticyclonic warm-core rings moving southward. The Vincennes, Poinsett, West and East Sabrina are cyclones. Should this be reconciled, e.g. with the narrower anticyclonic flows found in between?

The term mCDW was first coined by Countryman in the early 1960s while describing the dilution of CDW entering the Ross Sea, and thus used only over the shelf. Therefore I don't think it is correct to say (line 131) "inflow of offshore=origin mCDW".

The bathymetry shown here, specifically for the Dalton Depression inshore (line 163-165) is overly simplified and inaccurate, as revealed by the extensive multibeam survey during NBP14-02.

Whereas it is correct to say that in some shelf sectors dense Shelf Water is formed in the winter as the result of sea ice production within polynyas that is not the case within the Dalton Polynya (line216), and mCDW directly influenced by that process to form SW is even more unrealistic here: mCDW lies at the bottom!

Reviewer #3 (Remarks to the Author):

Summary

Totten Ice Shelf has higher than average basal melt rates for the East Antarctic region, and recent hydrographic observations by Rintoul et al 2016 and Hirano et al 2020 show warm mCDW at the ice fronts, which is likely to be driving that melting. This paper presents hydrographic observations presented which are used to show a mechanism by which CDW is transported from the offshore ACC to the shelf break, an upstream step which must occur before heat can be delivered to the ice shelf itself. The authors show that a series of cyclonic eddies offshore of TIS transport ocean heat poleward. They do this by pointing out that warm cores of mCDW, which extend close to the continental slope, are collocated with the eastern sides of eddies where the current is directed toward the shelf.

This paper is very well written, its purpose and results are clearly articulated, and it will certainly be a useful contribution to the field. However, there are some points I believe should be addressed before it is published.

Comments/Suggestions

(1) The authors claim that the eddy-induced transport plays a critical role in bringing ocean heat to the ice shelf, but they do not quantify how much heat is actually transported. How, then, can we understand the relative importance of this mechanism? Could the authors provide an estimate of the melt rate equivalent of the heat flux shown in the section plots? How does that compare to the melt rates determined by Rignot et al 2013?

(2) The authors claim that these results suggest that mCDW inflows are continual, but they do not provide strong evidence that the presence of mCDW at the eddy edges is consistent. The semi-permanent presence of the eddies is well-documented, but the hydrographic observations here are from a single cruise. Can the authors point to further evidence that the hydrographic sections shown here are typical?

(3) Can you add an error estimate to the velocity calculations? How strong are tides in the area? How much of an impact could they have on the density profile on which geostrophic velocities (and, therefore, absolute velocities) are based?

(4) The Section labels on Figure 1 are helpful for orienting the section plots shown in Figures 4 and 5. It would be even more helpful to also include these labels in Fig. 2b, since main results of the paper rely on the relationship between the current velocities and potential temperatures. I found myself having to look back and forth between Figs. 1 and 2 in order to determine whether water was moving onshore or offshore for a particular meridional section.

Lines 20-23: The wording is confusing. Which is atypical – the warm ocean-cryosphere interactions or the cyclonic circulation? It also doesn't seem to follow directly that such atypical conditions would eventually influence the global climate. Could you clarify and elaborate on this statement?

Line 168-170: Include citation for this claim. Is this also citation #17?

Response to the specific comments and suggestions from Reviewer #2

We very much appreciate your constructive and helpful comments. Your comments were invaluable for improving our manuscript. Our response to each comment is written in red italic and we have highlighted the changes made to the revised manuscript (yellow markers). We have also made and highlighted the changes other than those pointed out by the reviewers (light blue markers).

Reviewer #2 (Remarks to the Author):

Review of "Poleward eddy-induced warm water transport across a shelf break off Totten Ice Shelf, East Antarctica" by Hirano et. al.

This work presents a detailed description of the characteristic mesoscale stratification and circulation over the continental slope off Sabrina Coast, East Antarctica. A thorough analysis of closely-spaced CTD stations across and along the slope provides robust evidence of a persistent zonal train of large (O ~100-250 km) cyclonic "eddies" located between the shelf break and the southern boundary of the Antarctic Circumpolar Current (ACC). Along the eastern limbs of these subpolar cyclones Lower Circumpolar Deep Water (UCDW) drawn from the ACC is brought to the Antarctic Slope Current (ASC), where its extreme properties are attenuated more rapidly to produce Modified CDW (mCDW). The corresponding northward return flows of mCDW (below sill depths) are observed at the eddies western limbs. The authors correctly point out that mCDW remnants observed farther inshore, below sill depths, must result from complex sub-mesoscale interactions between eddies and topographic irregularities along the shelf break.

I find this work acceptable for publication in Communications Earth & Environment. The following comments are mostly suggestions and clarifications that might assist the authors while preparing the final version of this publication.

- *We are happy to have your favorable assessment. We have made revisions to the manuscript based on your helpful suggestions. Please see below for a detailed response to each comment.*

Title: I would reword "Poleward ... across a shelf break...", since the description is more of the cross-slope fate of warm CDW within multiple small and persistent subpolar cyclones.

- *Thank you pointing this out. We have discussed again whether the title properly represents the contents of the paper. Since each word in the title appropriately state "where" and "what kinds of phenomena" are mainly focused on in this paper, we came to conclusion that we do not necessarily need to change the title of this manuscript.*

I believe this work deals with warm waters being transported cyclonically in the study area, but I would argue that there is no discussion of how much heat is transported across the slope, i.e. what is the net poleward heat transport?

- *As you pointed out, there were no quantitative discussions of eddy-induced heat transport in the original manuscript. Based on your suggestion, we have added a discussion on the poleward heat transport estimated at the eastern part of the eddy (i.e., the southward flowing area).* ***(line: 198-213 & 341-348 (newly added Methods section))***

  Although the estimate is an order of magnitude larger than the heat flux required for TIS basal melting, this is a reasonable estimate when considering redistribution processes of the ocean heat transported into the continental shelf (e.g., water-mass modification and northward return flow). Thus, it is also reasonable to conclude that eddy-induced poleward heat transport plays an essential role as an offshore process that leads to TIS basal melting. However, it is difficult to estimate the poleward "net" heat transport across the slope due to eddies only because our observations could not capture the entire eddy region (especially around the southern part of the eddies).

Eddy poleward oceanic heat transport across the ACC is often associated to anticyclonic warm-core rings moving southward. The Vincennes, Poinsett, West and East Sabrina are cyclones. Should this be reconciled, e.g. with the narrower anticyclonic flows found in between?

- *As you mentioned, previous studies discussed the role of "large"-scale and mesoscale eddies (typically with an order of few tens kilometers spatial scale), including a form of anti-cyclonic warm-core eddies, on the poleward heat transport across/from the ACC region (e.g., Ansorge et al., 2015; Meredith, 2016; Gille et al., 2016). However, we use monthly-mean 0.2° × 0.2° satellite-derived dynamic ocean topography (DOT) data (Mizobata et al., 2020), and the dataset does not clearly reveal the significant southward motions of anti-cyclonic eddies. Moreover, the dataset's spatiotemporal resolution is not enough to capture the mesoscale processes. In reality, however, it is considered that such mesoscale eddies also contribute to the poleward heat transport across/from the ACC region around the northern edges of the cyclonic eddies; we have added the discussion on this matter.* ***(line: 176-181)***

The term mCDW was first coined by Countryman in the early 1960s while describing the dilution of CDW entering the Ross Sea, and thus used only over the shelf. Therefore I don't think it is correct to say (line 131) "inflow of offshore-origin mCDW".

- *As you pointed out, the more recent Ross Sea paper (Orsi & Wiederwohl, 2009, DSR II) also defines mCDW as CDW that inflows onto the continental shelf (see table below).*

Table 1
Water mass definitions. Shelf/slope 700 m demarcation refers to water depth.

γ^n layer (kg m^{-3})	Slope (>700 m)	Shelf (<700 m)	Properties
Top (L1: <28.0)	AASW	AASW	
Middle (L2: 28<γ^n<28.27)	CDW	MCDW	
Bottom (L3: >28.27)	AABW	MSW	$\theta > -1.85$ °C
		SW	$\theta < -1.85$ °C
		HSSW	$S > 34.62$
		LSSW	$S < 34.62$
		ISW	$\theta < -1.95$ °C

Water mass definitions by Orsi & Wiederwohl (2009)

However, in the Indian Sector of the Southern Ocean, CDW is typically termed "modified" CDW (mCDW) south of the Southern Boundary of the ACC (corresponding to the southward limit of the subsurface 1.5°C isotherm, Orsi et al., 1995) (e.g., Bindoff et al., 2000, DSR II; Williams et al., 2010, DSR II; Williams et al., 2010, JGR-Ocean; Meijers et al., 2010, DSR II). For reference, Fig. 2 of Williams et al. (2010, DSR II) is shown below. Based on the water mass definition for the Indian Sector, it is reasonable to say "inflow of offshore-origin mCDW" because our survey area (63°S and southward) is located south of the Southern Boundary of the ACC (shown as a pink line in Fig. 2).

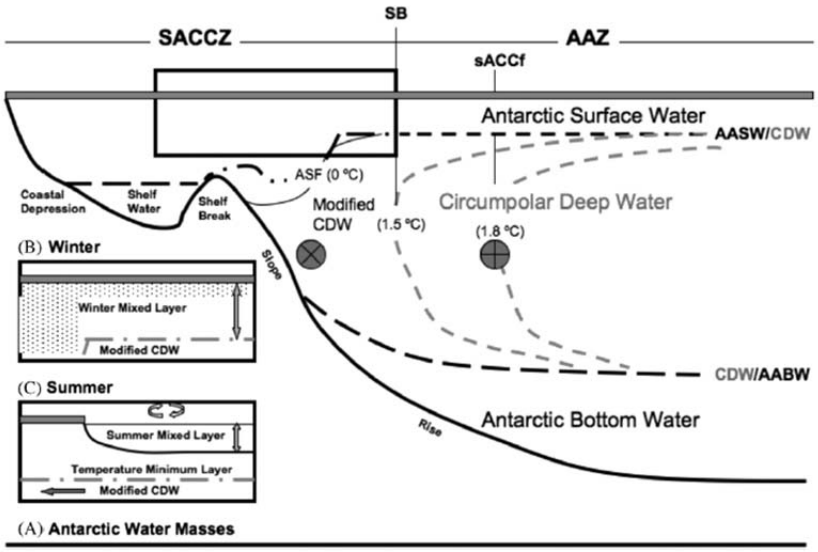

Fig. 2. Meridional schematic of East Antarctic water masses after Williams et al. (2008). The Zone South of the ACC (SACCZ) and the Antarctic Zone (AAZ) from (Pollard et al., 2002) as shown. The SB and sACCf are as defined in Orsi et al. (1995). Flow into the page (X-symbol) on the continental slope is the westward Antarctic Slope Current, flow out of the page (+-symbol) is the eastward sACCf. Inset (b) wintertime stratification over the shelf break and upper continental slope and inset (c) is for the summertime stratification.

Schematics of water mass in the Indian Sector of the Southern Ocean off East Antarctica (Fig.2 of Williams et al., 2010, DSR II)

The bathymetry shown here, specifically for the Dalton Depression inshore (line 163-165) is overly simplified and inaccurate, as revealed by the extensive multibeam survey during NBP14-02.

- *We agree that the shape of the depression represented by IBCSO bathymetric data is very simple, compared with that by the NBP 14-02 multibeam data (e.g., Fernandez et al., 2018, Geomorphology). In this study, we discuss the relationships between bathymetric features and the inflows of offshore warm water, by comparing the relevant previous studies (Nitsche et al., 2017; Silvano et al., 2019). They both showed the bathymetric map based on the IBCSO dataset, so that we dared to use the same IBCSO dataset to compare with these papers. However, we think we should state that "the depression's bathymetric feature based on IBCSO data is much oversimplified than realistic as demonstrated by the multibeam bathymetric data (e.g., Fernandez et al., 2018)." **(line: 184-186)***

Whereas it is correct to say that in some shelf sectors dense Shelf Water is formed in the winter as the result of sea ice production within polynyas that is not the case within the Dalton Polynya (line216), and mCDW directly influenced by that process to form SW is even more unrealistic here: mCDW lies at the bottom!

- *Thank you for pointing this out. We agree that our description here is not perfectly precise for the Dalton Polynya, where warm mCDW is observed during autumn to winter, as demonstrated by the in-situ mooring observation data (Silvano et al. 2018). This clearly indicates the convection in Dalton Polynya can not ultimately reach the seafloor. However, we can argue that the mixed layer depth (i.e., cold winter water thickness) seasonally develops due to deepening of vertical convection associated with enhanced sea-ice production especially from autumn to winter. Such seasonal deepening of overlying cold water possibly modifies mCDW thickness, in other words, subsequent heat flux beneath the Totten Ice Shelf. So, we have rephrased this part. **(line: 252-256)***

Response to the specific comments and suggestions from Reviewer #3

We very much appreciate your constructive and helpful comments. Your comments were invaluable for improving our manuscript. Our response to each comment is written in red italic and we have highlighted the changes made to the revised manuscript (yellow markers). We have also made and highlighted the changes other than those pointed out by the reviewers (light blue markers).

Reviewer #3 (Remarks to the Author):

Summary

Totten Ice Shelf has higher than average basal melt rates for the East Antarctic region, and recent hydrographic observations by Rintoul et al 2016 and Hirano et al 2020 show warm mCDW at the ice fronts, which is likely to be driving that melting. This paper presents hydrographic observations presented which are used to show a mechanism by which CDW is transported from the offshore ACC to the shelf break, an upstream step which must occur before heat can be delivered to the ice shelf itself. The authors show that a series of cyclonic eddies offshore of TIS transport ocean heat poleward. They do this by pointing out that warm cores of mCDW, which extend close to the continental slope, are collocated with the eastern sides of eddies where the current is directed toward the shelf.

This paper is very well written, its purpose and results are clearly articulated, and it will certainly be a useful contribution to the field. However, there are some points I believe should be addressed before it is published.

- *We are happy to have your favorable assessment. We have made revisions to the manuscript based on your helpful suggestions. Please see below for a detailed response to each comment.*

Comments/Suggestions

(1) The authors claim that the eddy-induced transport plays a critical role in bringing ocean heat to the ice shelf, but they do not quantify how much heat is actually transported. How,

then, can we understand the relative importance of this mechanism? Could the authors provide an estimate of the melt rate equivalent of the heat flux shown in the section plots? How does that compare to the melt rates determined by Rignot et al 2013?

- *As you pointed out, there were no quantitative discussions of eddy-induced heat transport in the original manuscript. Based on your suggestion, we have added a discussion on the poleward heat transport estimated at the eastern part of the eddy (i.e., the southward flowing area). (**line: 198-213 & 341-348 (newly added Methods section)**)*

  Although the estimate is an order of magnitude larger than the heat flux required for TIS basal melting, this is a reasonable estimate when considering redistribution processes of the ocean heat transported into the continental shelf (e.g., water-mass modification and northward return flow). Thus, it is also reasonable to conclude that eddy-induced poleward heat transport plays an essential role as an offshore process that leads to TIS basal melting. However, it is difficult to estimate the poleward "net" heat transport across the slope due to eddies only because our observations could not capture the entire eddy region (especially around the southern part of the eddies).

(2) The authors claim that these results suggest that mCDW inflows are continual, but they do not provide strong evidence that the presence of mCDW at the eddy edges is consistent. The semi-permanent presence of the eddies is well-documented, but the hydrographic observations here are from a single cruise. Can the authors point to further evidence that the hydrographic sections shown here are typical?

- *As you pointed out, one might think that evidence on the "semi-permanent" eddy-induced mCDW inflows is weak with one snapshot from a single cruise. Therefore, we have added more section data obtained by another cruise of the Japanese Antarctic Research Expedition (JARE), by adding a new co-author (Takeshi Tamura) who is responsible for the JARE observation. The newly added potential temperature sections also further gives us the evidence on this issue and are now shown as Supplemental*

*figures (**Fig. S2-S3**). Also, we have added one relevant explanation to this. (**line: 115-118 & 306-308**)*

(3) Can you add an error estimate to the velocity calculations? How strong are tides in the area? How much of an impact could they have on the density profile on which geostrophic velocities (and, therefore, absolute velocities) are based?

- *According to Rintoul et al. (2016), tidal amplitudes at the TIS ice front were assumed to be ±5 cm/s, so it is reasonable to consider that the barotropic tidal velocities around the deeper continental slope have smaller amplitudes. In addition, CTD's density profile reflects only the baroclinic component and does not inherently include the tidal effect. Also, the tidal component is already removed by the tidal correction (FES2004, Lyard et al., 2006) when the DOT is calculated (Mizobata et al., 2020).*

  *For clarity, we have modified the Methods section by adding descriptions regarding the tidal correction (**line: 327-333**). The tidal-related error in the estimation of absolute velocity can be considered negligible, if any.*

  (4) The Section labels on Figure 1 are helpful for orienting the section plots shown in Figures 4 and 5. It would be even more helpful to also include these labels in Fig. 2b, since main results of the paper rely on the relationship between the current velocities and potential temperatures. I found myself having to look back and forth between Figs. 1 and 2 in order to determine whether water was moving onshore or offshore for a particular meridional section.
- *Sorry for making you tired of the inconvenience. Based on your suggestion, we have added labels of Section 1-3 in **Fig.2b**.*

  Lines 20-23: The wording is confusing. Which is atypical – the warm ocean-cryosphere interactions or the cyclonic circulation? It also doesn't seem to follow

directly that such atypical conditions would eventually influence the global climate. Could you clarify and elaborate on this statement?

- *Here, we intended to state that "warm ocean-cryosphere interaction" is atypical for East Antarctic ice shelves, and such atypical interaction might be achieved by offshore cyclonic circulation. Also, the "semi-permanent" feature of the cyclonic circulations that play a vital role in poleward heat transport toward the ice shelves is influential to the global climate. For clarity, we have rephrased this part. (**line: 29-32**)*

Line 168-170: Include citation for this claim. Is this also citation #17?

- *Thank you for pointing this out. Yes, this claim should also be with citation #17 (Silvano et al. 2019), and we have included Silvano et al. (2019) here. (**line: 190**)*

19th May 21

Dear Dr Hirano,

Your manuscript titled "Poleward eddy-induced warm water transport across a shelf break off Totten Ice Shelf, East Antarctica" has now been seen by our reviewer 3, whose comments appear below. In light of their advice I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Heike Langenberg, PhD

Chief Editor
Communications Earth and Environment

On Twitter: @CommsEarth

REVIEWERS' COMMENTS:

Reviewer #3 (Remarks to the Author):

The authors have addressed all my comments from the first submission and I would recommend this manuscript for publication.

Our sincere gratitude to two reviewers:

We heartily thank you for your constructive and helpful comments up to this point, which was invaluable for improving our manuscript.

REVIEWERS' COMMENTS:

Reviewer #3 (Remarks to the Author):

The authors have addressed all my comments from the first submission and I would recommend this manuscript for publication.
