Cover letter

Dear Editor:

We thank you and two anonymous reviewers very much for the constructive comments and suggestions for the paper 'Ensemble-based estimation of sea-ice volume variations in the Baffin Bay' submitted to *the Cryosphere*. They are very valuable and very helpful for improving our manuscript. We have made a substantial revision according to the comments and suggestions from the editor and the two reviewers, and replied to them one by one below.

Qinghua Yang

On behalf of all the authors

Responses to the editor

Dear editor,

We appreciate your great efforts to improve this manuscript. Followed your comments and also the #1 comment from referee one, we have used OSISAF drift to calculate the sea ice volume (SIV) fluxes individually. However, we found that the mean southward and northward velocity from OSI-405 are much higher than NSIDC drift (V4) though the annual cycles of two drift data are similar (shown in Figure 1 in Response letter #1). This overestimation can be attributed to its (OSI-405) reduced spatial coverage in lower latitudes and rough mesh grid (62.5 km) in the Baffin bay (e.g., especially along the south gate in this study), because this causes only a few sea ice floes with higher velocity located in the center of the Davis Strait (i.e., south gate) can be measured. This would induce some unquantifiable errors calculating SIV fluxes in Baffin Bay if OSISAF drift is solely used. We also tried to average the NSIDC drift and OSISAF drift, but systematic differences between them are found. Moreover, the new version of NSIDC drift performs much better than the previous version (Hiroshi Sumata and Frank Kauker, personal communication). So, based on the above reasons, we decide to only use NSIDC drift to estimate the sea ice volume fluxes in the Baffin Bay.

Again, we thank you very much for your time and great efforts to improve this manuscript.

Qinghua Yang
On behalf of all the authors

Responses to referee #1

General Comments:

This study provides a more thorough assessment of annual sea ice volume changes in and solid ice freshwater flux variations across Baffin Bay than previous work. Combining several state-of-the-art sea ice models, some including data assimilation, enables the authors to estimate an uncertainty envelope around sea volume changes in the absence of in-situ or satellite observations. The amount of sea ice forming thermodynamically in Baffin Bay and the volume of freshwater exported from the bay into the Labrador Sea have critical downstream impacts on deep water formation and the overturning circulation of the North Atlantic. So, I expect these results will be valued in the climate and physical oceanography communities.

I have made a few comments regarding the choice of datasets and methods used, particularly relating to use of only a single ice motion dataset and rejecting the use of satellite thickness observations. It would also be great to include more context for the calculated solid ice freshwater fluxes. Otherwise the manuscript seems to be in a good state and my remaining comments/edits are all quite minor.

Dear Reviewer:

We would like to thank you for the constructive comments to improve this manuscript. We agree that adding more satellite thickness observations will improve the estimations of sea ice fluxes and the local ice volume variations. Thus, we added satellite-based sea ice thickness observations (Landy et al., 2017) to improve our estimations as suggested. We also tried to add OSISAF drift to calculate the sea ice fluxes following comment #1 and editor's suggestion. However, because of its limited coverage and rough mesh grid in the bay, the usage of this data may cause some unquantifiable errors. And because the new version of NSIDC drift performs much better according to Hiroshi Sumata and Frank Kauker (*pers. com.*), we decided to use NSIDC drift only to calculate the sea ice fluxes. Because the sea ice volume variations are also estimated based on the satellite observations in the revised text, the title of our manuscript has been be modified as "Ensemble-based estimation of sea-ice volume variations in the Baffin Bay". Furthermore, we discussed the freshwater budget in the Baffin Bay and Labrador Sea in the discussion part (Section 4) of our revised manuscript and we compared our estimate of the freshwater volume stored in ice with estimate of previous studies. Additionally, we included maps of the monthly mean freshwater fluxes as well as the freshwater volume that is stored in the sea ice in the bay in our revised manuscript.

The specific responses and revisions are elucidated below shown in blue font for clarity.

Corresponding Author: Qinghua Yang

Email: yangqh25@mail.sysu.edu.cn

Specific comments:

Point 1: Three model ice volume products are used but only one drift product. Alternative drift vectors from OSISAF and/or Kimura et al could also be used to improve the determination of the volume flux uncertainty envelope. Line 62, is OSISAF not available year-round in BB? If other products are not available year-round or have full coverage over BB, can you estimate the uncertainty envelope for the ice motion for the seasons/region where they do overlap and use that in your determination of overall error?

Response 1: We agree with this constructive comment and decided added the well-validated low resolution OSISAF drift (OSI-405) to consolidate our estimates of sea-ice volume (SIV) fluxes in the bay. We chose the OSISAF drift rather than the KIMURA drift because the OSISAF and NSIDC drift data are proved to have valid performance in the Arctic (Sumata et al., 2014) and OSISAF drift data performs better than other data (i.e., NSIDC, CERSAT and KIMURA). However, for the study period, OSISAF drift data is only available for freezing season (October-April) while the summer season drift data is provided since 2017 (http://www.osi-saf.org/?q=content/sea-ice-products). Then we calculate the mean southward velocity over the northern inflow gate and southern outflow gate (Figure 1), and the SIV fluxes based on OSISAF drift were also calculated (not shown). The mean southward velocity from OSISAF is about 5.83 km d^{-1} over the north gate and 9.18 km d^{-1} over the south gate during the freezing season, respectively. However, the mean southward velocity based on NSIDC is only about 3.05 km d^{-1} and 3.69 km^{-1} during the freezing season, respectively. Results show that the mean southward and northward velocity from OSI-405 are much higher than NSIDC drift (V4) though the annual cycles of these two drift data are similar. This overestimation can be attributed to its (OSI-405) reduced spatial coverage in lower latitudes and rough mesh grid (62.5 km) in the bay (e.g., especially along the south gate in this study) which cause only a few sea ice floes with higher velocity located in the centre of the Davis Strait (i.e., south gate) can be measured. As previously discussed, it may induce some unquantifiable errors in Baffin Bay if OSISAF drift is solely used. The coverage of OSISAF and NSIDC drift in the freezing season of 2011 is shown in Figure 2 as an example.

Then, we have tried to average the OSISAF drift and the NSIDC drift during the freezing season to get an ensemble mean sea ice drift. And for the melting season (May-September), only NSIDC drift was used. Nevertheless, this method will also cause some bias because the systematic differences between NSIDC and OSI ice drift are found (as example in Figure 1). The inappropriateness of this method was also pointed out by the editor. Moreover, the new information that we got is the new version of NSIDC drift performs much better according to Hiroshi Sumata and Frank Kauker (*pers. com.*). So, based on above reasons, we decide to only use NSIDC drift to estimate the sea ice volume fluxes in the Baffin Bay.

All estimates of sea-ice volume (SIV) and of the fluxes have been recalculated with

NSIDC drift and the satellite-based sea ice thickness (will be discussed in Point 2) and the model ice thicknesses. The updated results are shown in in our revised manuscript. *(please see these updated results in our revised manuscript)*

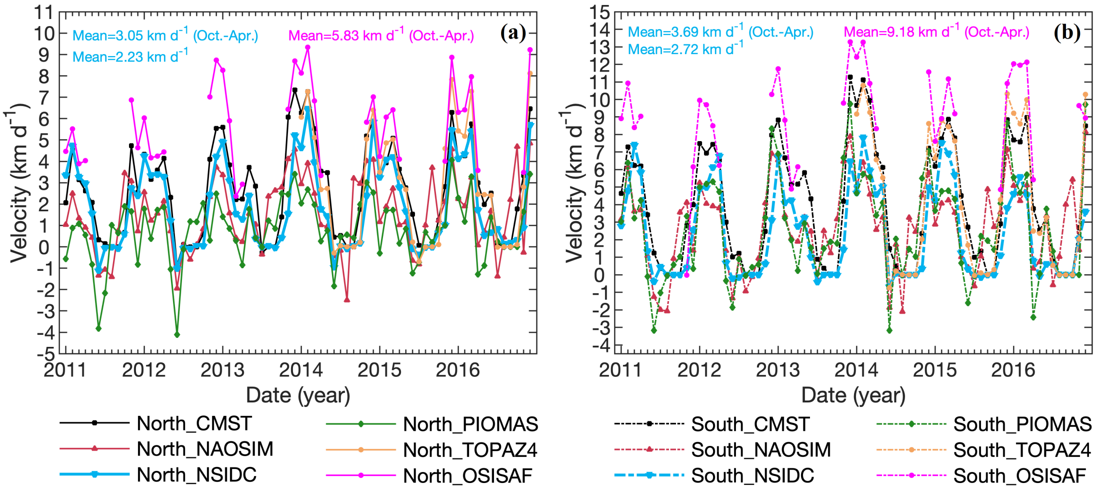


Figure 1. Monthly mean southward velocity over the northern inflow gate (a) and southern outflow gate (b), respectively.

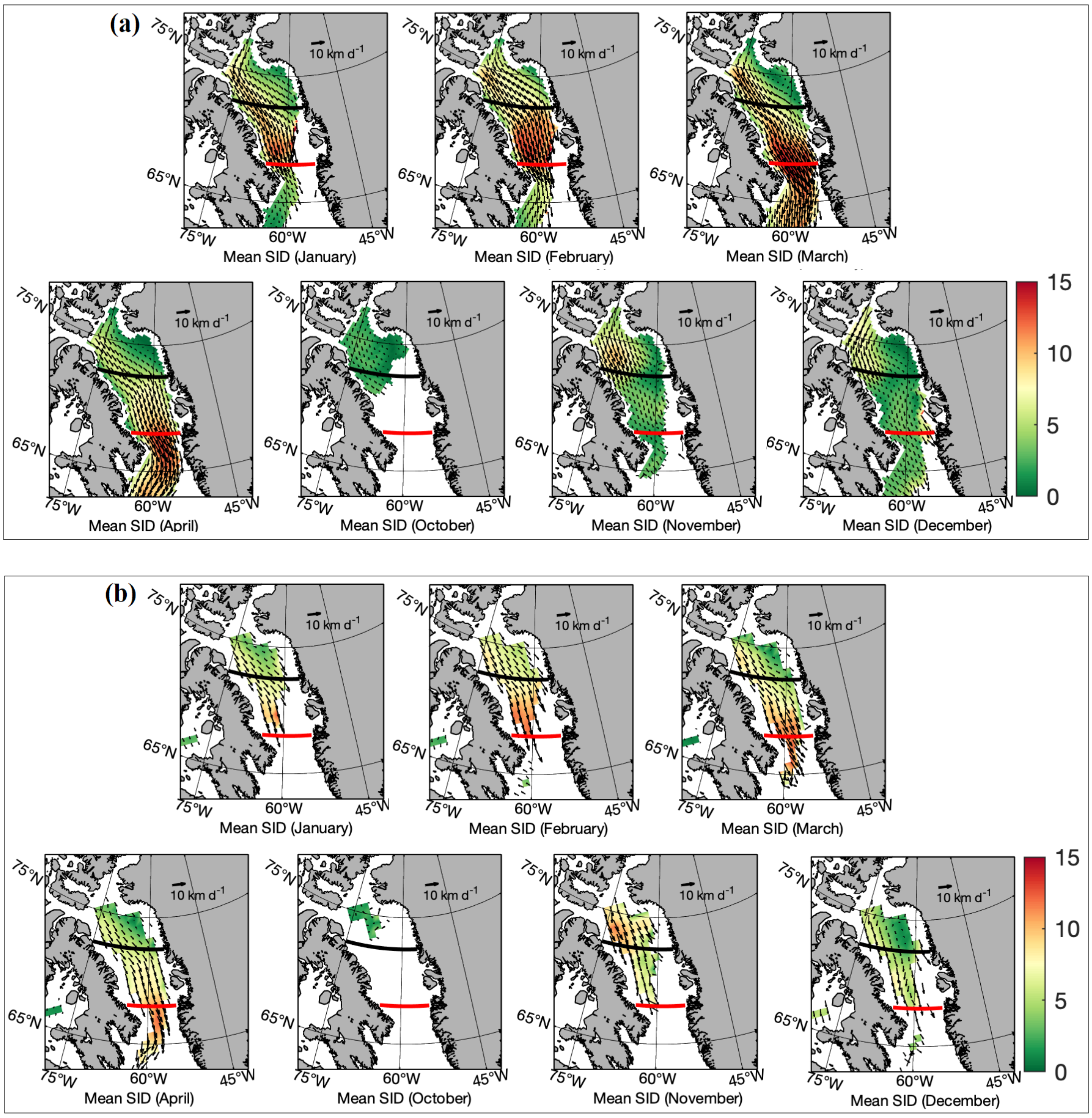


Figure 2. Monthly mean sea ice drift in the freezing months of 2011 from (a) NSIDC and from (b) OSISAF

Point 2: L59-60, in my opinion the SIT data from remotely-sensed observations have sufficient validity to compare with the model simulations. If there are clear biases that have been identified in Baffin Bay or in regions with similar sea ice regimes, then please discuss here. Otherwise I suggest to add a short comparison of the winter SIT evolution between the models, SMOS and CS2 or CS2SMOS, with the uncertainties of the observations illustrated, to gauge the validity of the models individually and as a collective. You may be able to discard one model in your ensemble, for instance, if it shows clear deviation from the satellite observations.

Respond 2: We agree that the remotely-sensed observations have sufficient validity in the Arctic Basin. However, in Baffin Bay, SMOS SIT is proved to underestimate because (1) SMOS only provides the valid SIT that is thinner than 1 m and (2) the 100% ice concentration assumption in the retrieval algorithm is not well justified (Tian-Kunze

et al., 2014; Tietsche et al., 2018). Moreover, sea ice in the Baffin Bay is dominated by seasonal thin ice and CS2 has large uncertainty in the area where SIT is thinner than 1 m (Figure 2, Ricker et al., 2017). Based on the above discussion, we decided not to use SMOS and CS2 or CS2SMOS to estimate the sea ice fluxes in Baffin Bay.
Instead, we choose a local satellite-based SIT product that calculates SIT from CS2 radar freeboard together with passive microwave (PMW)-derived snow depth and merges it with SMOS where the CS2 derived thickness is thinner than 1 m (Landy et al., 2017; Landy et al., 2019; Landy et al., 2020). To improve the estimation of the volume flux, the satellite-based SIT is jointly used with CMST, NAOSIM and PIOMAS SIT in an ensemble approach.

Point 3: I recommend adding greater depth to the discussion on Baffin Bay/Labrador Sea freshwater budget. How do your results for the freshwater volume stored in ice within Baffin Bay compare to past estimates? How about the solid ice flux across Davis Strait? More importantly what is the context of the solid ice fluxes within the full freshwater budget?
Respond 3: We agreed that more detailed discussions on Baffin Bay/Labrador Sea freshwater budget are very necessary. We now estimated the monthly mean freshwater volumes derived from SIV inflow, outflow and the net SIV flux (i.e., SIV inflow minus outflow). The estimations were shown in Figure S7, including the freshwater volume variation from sea ice growth/melting processes in the Baffin Bay. Also, the freshwater volume stored in ice within the Baffin Bay and the solid ice flux across Davis Strait are further compared with previous studies. Then we compared the freshwater melting from sea ice with the full freshwater budget as suggested.
Some discussions are shown as follows:
We converted the monthly mean sea-ice inflow and outflow as well as the net flux and the ice growth/melting into the freshwater volume fluxes (Fig. S7). It should be noted that the meltwater (from ice melting in the bay) released into Baffin Bay reached its maximum of 156 km^3 month^{-1} (i.e., 59 mSv) in July of 2015 while the maximal rate of sea-ice production happened in January of 2015 leading about 65 km^3 freshwater stored in sea ice. The maximum amount of freshwater stored in sea ice in Baffin Bay is about 240 km^3 in March/April. However, it is estimated by Landy et al. (2017) to be maximal in April (445 km3). Because the area of our defined region is only about half of that in Landy et al. (2017), the smaller estimated freshwater storage may mostly attribute to the smaller study area. The maxima of freshwater inflow and outflow take place in the period of January to March and February to April, respectively. The maximum net freshwater flux entering the Baffin Bay through the north gate is about 53 km^3 month^{-1} (i.e., 20 mSv) in December of 2014 while the maximum of freshwater flux derived from ice outflow through Davis Strait is about 89 km^3 month^{-1} (i.e., 34 mSv) in March of 2015. The annual freshwater flux through the Davis Strait ranges from 172 km^3 (i.e., 5 mSv) in 2016 to 326 km^3 (i.e., 10 mSv) in 2015. Annually, the mean freshwater flux derived from SIV outflow is about 249 km^3 year-1 (i.e., 8 mSv) which is about 9% of the net liquid freshwater flux (93 mSv, Curry et al., 2014) through the Davis Strait. Moreover, the mean freshwater flux estimated in this study is slightly

smaller than the estimation based on ULS SIT observations (10 mSv; Curry et al., 2014). ***(More details are shown in the Discussion part of our revised manuscript)***

Point 4: I would suggest having another careful check through the text, as there are quite a few minor spelling mistakes and grammatical errors.
Respond 4: Thanks for this comment. We have carefully checked through this manuscript and we believe that the readability of our manuscript has been largely improved.

Point 5: Line 18: '…largest SIV outflow in spring of 2014' why?
Respond 5: We also noticed this difference (non-corresponding peaks) between inflows and outflows. This discordance can be attributed to the different time series of sea ice thickness (SIT) and drift along the north gate and the south gate. For example, the maximum of sea ice drift along the south gate reached its peak value during the winter of 2013, though the mean SIT during the winter of 2013 was relatively thinner than that in the spring of 2014.

Point 6: L20: What about the freshwater budget? How much ice meltwater enters the ocean over the melt season? This is the key missing feature of the abstract, with respect to freshwater and deep water formation.
Respond 6: As suggested, we added this key feature in the abstract:
In the melting season, there is about 268 km^3 freshwater produced by local melting of sea ice in the Baffin Bay. In the annual mean, the mean fresh water converted from SIV outflow that enters the Labrador Sea is about 249 km^3 year^{-1} (i.e., 8 mSv), while it is only about 9% of the net liquid freshwater flux through the Davis Strait. The maximum fresh water flux derived from SIV outflow peaks in March with the amount of 65 km^3 (i.e., 25 mSv). ***(please see P1 line 28-32 in our revised manuscript)***

Point 7: L23: Draining off what? The Greenland Ice Sheet, liquid freshwater in the ocean proper, both..?
Respond 7: Both the Greenland Ice Sheet glacial melt and liquid freshwater can affect the fresh water budget in the Baffin Bay. We realized the formerly ambiguous description. To avoid confusion, we modified our description as:
This bay serves as an important pathway of southward flowing and cold freshwater draining off from the Arctic into the North Atlantic Oceans (Curry et al., 2010; Curry et al., 2014). Freshwater outflows through Davis Strait entering the Labrador Sea are integrated from Canadian Arctic Archipelago and west Greenland glacial runoff, river inputs, sea ice melt water and precipitation (Curry et al., 2010; Curry et al., 2014; Tang et al., 2004). ***(please see P2 line 35-38 in our revised manuscript)***

Point 8: L31: Large errors with respect to what? Other regions or to other model-based thickness estimates?
Respond 8: We refined this description as:
However, seasonal thin sea ice in the bay is dominating and satellite-based ice thickness

has large errors in the bay with respect to other regions in the Arctic Basin. ***(please see P2 line 48-50 in our revised manuscript)***

Point 9: L34-35. Can you define the directions of these fluxes?

Respond 9: We refined this sentence to *'In a recent study, Bi et al. (2019) analysed the sea-ice area fluxes in Baffin Bay on a long-term time period and the increasing trend of the annual sea-ice area flux are found to be 38.9 × 10^3 km^2 decade^{-1} for the inflow through the north gate, 7.5 × 10^3 km^2 decade^{-1} for the inflow through Lancaster Sound and 82.2 × 10^3 km^2 decade^{-1} for the outflow through the south gate (Davis Strait), respectively.'* ***(please see P2 line 51-55 in our revised manuscript)***

Point 10: L45-46. This argument requires more detailed explanation.

Respond 10: We detailed this description as follows:

The sea-ice thermodynamic processes are closely related to the desalination of seawater and the freshwater budget in the Baffin Bay. For instance, during sea-ice freezing, salt is discharged into the surface ocean water leading to denser and saltier conditions which destabilizes the water column. On the other hand, when the sea ice melts fresh/hyposaline water is drained into the surface water causing desalination of the surface water and, consequently, stabilizes the water column. ***(please see P3 line 67-70 in our revised manuscript)***

Point 11: L50. I am not convinced the satellite based products are inappropriate to be used in this region. Can you provide an argument with supporting evidence why satellite measurements, including SMOS and/or altimetry, cannot be used here? (I do understand the satellite products only capture the winter ice growth season, so cannot be used to determine the full annual ice volume budget, which is in my mind a better reason not to use them than their apparently limiting uncertainties). You also state that the spatial distributions of model SIT are similar to that derived from satellites in Landy et al 2017; so why then are the satellite observations inappropriate to be used?

Respond 11: As we stated in response 2, we do agree with the referee that the remotely-sensed observations have sufficient validity in the Arctic Basin. However, in the Baffin Bay, SMOS SIT is proved to be underestimated because (1) SMOS only provides the valid SIT that thinner than 1 m and (2) the 100% ice concentration assumption during the data retrieval is not fully filed (Tian-Kunze et al., 2014; Tietsche et al., 2018). In addition, the sea ice in the Baffin Bay is dominated by seasonal thin ice, CS2 thus has large uncertainties in the area where SIT is thinner than 1 m (Figure 2, Ricker et al., 2017).

In a recent study of Landy et al. (2017), they developed a locally merged sea ice thickness data that calculated from CS2 radar freeboards and PMW snow depths, then merged with SMOS where the mean CS2 thickness is <1 m. This data is applied to estimate the sea ice variations in the Baffin Bay (Landy et al., 2017). Therefore, in the revised version of manuscript, we will add this data to calculate the sea ice volume fluxes and variations to improve the determination of the volume flux as suggested. The updated results are shown in the Supplement part of this response letter and they are also updated in our revised manuscript. ***(please see these updated figures in the Supplement materials and our revised manuscript)***

Point 12: L53. Spell out the model acronyms.

Respond 12: We showed both the full name and acronyms of these reanalysis (i.e., combined model and satellite sea ice thickness (CMST), Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS), North Atlantic/Arctic Ocean Sea Ice Model (NAOSIM) and Towards an Operational Prediction system for the North Atlantic European coastal Zones (TOPAZ4)) in our revised version.

Point 13: L54-59. Please list the exact SIC, SIT and SST products used for assimilation into the models, as this clearly affects their interpretation.

Respond 13: Thanks for your suggestions. *CMST is based on the Massachusetts Institute of Technology generation circulation model (MITgcm) and SMOS SIT from University of Hamburg, CryoSat-2 SIT from AWI and Special Sensor Microwave Imager/Sounder (SSMIS) ice concentration processed at IFREMER are assimilated (Mu et al., 2018a) while PIOMAS assimilates SIC from NSIDC near-real time product and sea surface temperature (SST) from the NCEP/NCAR Reanalysis (Zhang and Rothrock, 2003; Schweiger et al., 2011).".* ***(please see the data description in our revised manuscript)***

Point 14: L108. Why are the CryoSat-2 or CS2SMOS SIT data inappropriate in Baffin Bay? What does the strong seasonality have to do with it, and what do you mean by that?

Respond 14: As we stated before, sea ice in the Baffin Bay is dominated by seasonal thin ice and CS2 has large uncertainty in the area where SIT is thinner than 1 m (Figure 2, Ricker et al., 2017). Moreover, in the Baffin Bay, SMOS SIT is proved to be underestimated because (1) SMOS only provides the valid SIT that thinner than 1 m and (2) the 100% ice concentration assumption during the data retrieval is not fully filed (Tian-Kunze et al., 2014; Tietsche et al., 2018). We realized the previous description is ambiguous, and we refined our description in the revised texts.

Point 15: L118. How were the drift observations validated? With in situ measurements?

Respond 15: The daily mean NSIDC drift observations are assessed with high-resolution (~ 100 m) Envisat wide-swath (~ 450 km) SAR observations and IABP buoy measurements (in the Arctic Ocean) from January 1979 to December 1994 (Bi et al., 2019). Their result shows (Figure 2, 3 and 4; Bi et al., 2019) that the NSIDC drift slightly underestimates the ice drift with a mean bias of -0.68 km day^{-1} while has a high correlation (R=0.87) with SAR drift observation. To clarify our description, we refined this sentence as:

The NSIDC data set has been recently validated with high-resolution Envisat wide-swath SAR observations and IABP buoy measurements by Bi et al. (2019). Comparing with the observed sea ice drift that retrieved from high-resolution (~100 m) Envisat

Synthetic Aperture Radar (SAR) observations, the NSIDC drift slightly underestimates the ice drift with a mean bias of -0.68 km day-1, while it has a high correlation (R=0.87) with SAR drift (Bi et al., 2019). ***(please see P6 line 68-72 in our revised manuscript)***

Point 16: L153. I do think it is worth including the CS2 or CS2SMOS cycle in your comparisons here.
Response 16: We agreed that CS2 and CS2SMOS have sufficient validity in the Arctic Basin. However, sea ice in the Baffin Bay is dominated by seasonal thin ice and CS2 has large uncertainty in the area where SIT is thinner than 1 m (Figure 2, Ricker et al., 2017). Instead of using CS2 or CS2SMOS, we decided to use a locally merged data that calculated from CS2 radar freeboards and PMW snow depths, then merged with SMOS where the mean CS2 thickness is <1 m (Landy et al., 2017; Landy et al., 2019; Landy et al., 2020). With this newly produced regional data, the disparities between satellite-observed SIT and modeled SITs are reduced. The comparisons are shown in Figure S2 **(*also shown in Figure 2 in our revised manuscript*).**

Point 17: Fig 2. Can you explain why the CMST simulations how a 'flattening off' of sea ice volume increase at the end of winter, when NAOSIM and PIOMAS are still rising?
Response 17: We also noticed these disparities between CMST, NAOSIM, PIOMAS and satellite-based observations, and this 'flattening off' also noticed by previous studies (Mu et al., 2018a; Tilling et al., 2015). For instance, the Northern hemisphere sea ice volumes from PIOMAS and CryoSat-2 reach their maximums in April and March, respectively (Figure 2, Tilling et al., 2015). The same phenomenon was also observed in TOPAZ4 system (personal communication with Jiping Xie on FAMOS meeting, 2018, Norway). The current clue we know is that both CMST and TOPAZ4 assimilate CS2/SMOS thickness observations, while NAOSIM and PIOMAS not. Further comprehensive diagnostics are needed to clarify it.

Point 18: L165. 'cycle' rather than 'trend'?
Response 18: Agreed, we used 'cycle' instead of 'trend' as suggested.

Point 19: L193. What are the +/- as percentages?
Response 19: The *'+/-number'* indicates one standard deviation among the ensemble members, i.e., inflows and outflows from (1) CMST SIT and observed SID, (2) NAOSIM SIT and observed SID, (3) PIOMAS SIT and observed SID and (4) observed SIT and observed SID. To specify this, we added the necessary description in section 2.7 as: *And we use one standard deviation (i.e., +/-number) among these ensemble members to show the uncertainties of flux estimations in this study.* ***(please see P6 line 86-88 in our revised manuscript)***
Moreover, the reason that we did not applicate '+/-' as percentages is in order to keep consistent with previous studies (e.g., Bi et al., 2019; Min et al., 2019; Ricker et al., 2018; Spreen et al., 2020) so that the readers can easily compare these results.

Point 20: L200. What do you mean by 'reach a maximum in spring/winter with a mean value of…'? Confusing

Response 20: We rewrote our sentence with our updated results: *'On average, the maximum of ice inflow occurs in winter with a mean value of 236(±38) km^3 while usually the ice outflow reaches the maximum in spring with a mean value of 168 (±46) km^3.'.* ***(please see P9 line 270-273 in our revised manuscript)***

Point 21: L205. Can you explain why a constant factor of 0.8 is used and justify it? (It is not sufficient just to include a citation without deeper explanation)

Response 21: We added some more explanation for the adoption of constant factor of 0.8 as:

Furthermore, to quantify the fresh water imported into the Labrador Sea, an important area of deep water formation, we convert the SIV fluxes to the fresh water fluxes according to Spreen et al. (2020):

$$(1 - \frac{S_{ice}}{S_{ref}}) (\frac{\rho_{ice}}{\rho_{water}}) \approx 0.8,$$

(3)

where the sea ice salinity (S_{ice}) is assumed to be 4 psu, the reference seawater salinity S_{ref} is 34.8 psu, sea ice density (ρ_{ice}) is 901.3 kg m-3 and seawater density (ρ_{water}) is 1023.9 kg m-3 (Haine et al., 2015; Serreze et al., 2006). ***(please see P9 line 275-281 in our revised manuscript)***

Point 22: L206. Can you place this value of 271 km^3 yr^{-1} in context? What is that in Sv? How does it compare with literature values for the net liquid FW flux across approx. the same southern gate between Baffin Bay and the Labrador Sea from other studies?

Response 22: The results in our manuscript were updated following your suggestions. This sentence was also revised with our updated results: *The annual mean amount of freshwater flux that exported into the Labrador Sea derived from SIV flux is about 268 km^3 year^{-1} (i.e., 8 mSv). Relatively large fresh water fluxes are found from January to April peaking at 64 km^3 month^{-1} (i.e., 24 mSv) in March. The annual mean freshwater directly derived from ice meltwater in previous studies is in a range from 10 mSv (i.e., 331 km^3 year^{-1} of SIV; Curry et al., 2014) to 21.3 mSv (i.e., 873 km^3 year^{-1} of SIV; Tang et al., 2004) which is larger than our estimation.* ***(please see P9 line 281-286 in our revised manuscript)***

Further, the fresh water entering into the Labrador Sea that melts from sea ice is also discussed in our section 4 (Discussion section of our revised manuscript) as Point 3 described.

Point 23: L235. It is unclear what you mean by 'We thus speculate that the thick ice is exported from the Arctic since the higher ice velocity is also found in these areas'. What point are you making?

Response 23: We have refined our description as follows:

We notice that the ice thicker than 0.5 m is mostly located near the Nares Strait in

October companying with higher ice velocity (more than 10 km day^{-1}) identified near the Smith Sound and Lancaster Sound by CMST (figure not shown). We thus speculate that most of the thick ice may be exported from the Arctic since the higher ice velocity is also found in the corresponding area of the thick ice located (i.e., Nares Strait), and the faster ice is usually deemed to be a proxy for higher ice flux, which is also noticed in previous studies (Kwok, 2005, 2007). ***(please see P10 line 306-310 in our revised manuscript)***

Point 24: L228-234. How do your results compare with the cited studies? Are the net volume growth/melting terms similar or very different (accounting for disparities in the study area)?

Response 24: We added these comparisons with Landy et al. (2017) as suggested:

The annual mean sea ice growth rate in our study is 52 km^3 month^{-1} while it is about 87 km^3 month^{-1} estimated in a previous study (Table 3, Landy et al., 2017). Also, the monthly mean SIV variability in our study is smaller than that of Landy et al. (2017) which can be attributed to a different area of the study regions. ***(please see P11 line 320-322 in our revised manuscript)***

We needed to interpret that the net volume growth/melting terms in our study is very different from the previous study (Landy et al., 2017), because we excluded the net SIV flux (Q_{net}) in the calculation ($\frac{dV}{dt} = Q_{net} + (\frac{dV_{therm}}{dt} + \frac{dV_{resid}}{dt})$) while Landy et al. (2017) only calculated the regional SIV variation (assuming ice melts in situ). So, it is difficult to compare these two estimations in terms of net volume growth/melting. However, we further compared the satellite-based sea ice volume variation (provided by Landy et al.) with our modeled estimations (shown in Fig. S6). Then the ensemble-based SIV variation is averaged with the modeled results (i.e., CMST, NAOSIM and PIOMAS) and satellite observation. We also estimated the rate of ice production applying the similar method used in Landy et al. (Table 3, 2017), the rate of ice production is about 52 km^3 month^{-1} in our study while it is 87 km^3 month^{-1} (SR10 adding SR11) in Landy et al. (2017). Because the study area (SR10 adding SR11) in Landy et al. (2017) is much larger than ours, this disparity between these two studies can be mostly attributed to different defined area.

Point 25: L242. How do you know the drift is underestimated? Have you tried comparing with another product, e.g. OSISAF for at least the months and time period they overlap?

Response 25: It is proved that NSIDC drift present a mean bias of -0.68 km day^{-1} compared with SAR ice drift indicating that NSIDC drift is slightly slower (Figure 4, Bi et al., 2019). Also, Sumata et al., (2014) found that the monthly mean NSIDC drift was slightly slower than OSISAF drift and the spatial mean ice drift speed in the Arctic Ocean was also slightly slower than OSISAF, IABP/D and KIMURA ice drift data. Moreover, the sea ice volume export through the Fram Strait based on AWI CS2 sea ice thickness and NSIDC drift (version 3) shows a mean difference about -26 % comparing with that based on AWI CS2 sea ice thickness and OSISAF drift. However, the new version of NSIDC SID performs much better according to Sumata (*pers. com.*).

NSIDC drift is not compared with OSISAF drift in the previous version of this manuscript. So, following the referee's suggestions, we further added OSISAF drift into the intercomparison between NSIDC, CMST, PIOMAS, NAOSIM and TOPAZ4 ice drift. In our intercomparison (Figure 2), OSISAF SID is much larger than the NSIDC drift.

Reference

Bi, H., Zhang, Z., Wang, Y., Xu, X., Liang, Y., Huang, J., Liu, Y., and Fu, M.: Baffin Bay sea ice inflow and outflow: 1978– 1979 to 2016–2017, The Cryosphere, 13, 1025-1042, doi: 10.5194/tc-13-1025-2019, 2019.

Landy, J., C., Petty, A. A., Tsamados, M., and Stroeve, J. C.: Sea ice roughness overlooked as a key source of uncertainty in CryoSat-2 ice freeboard retrievals. J. Geophys. Res-Oceans., 125, e2019JC015820. doi: 10.1029/2019JC015820, 2020.

Landy, J., C., Tsamados, M., and Scharien, R., K.: A Facet-Based Numerical Model for Simulating SAR Altimeter Echoes From Heterogeneous Sea Ice Surfaces, IEEE T. Geosci. Remote, 57, 4164-4180, doi: 10.1109/TGRS.2018.2889763, 2019.

Landy, J., C., Ehn, J. K., Babb, D. G., Thériault, N., and Barber, D. G.: Sea ice thickness in the Eastern Canadian Arctic: Hudson Bay Complex & Baffin Bay, Remote Sens. Environ., 200, 281-294, doi: 10.1016/j.rse.2017.08.019, 2017.

Curry, B., Lee, C. M., and Petrie, B.: Volume, Freshwater, and Heat Fluxes through Davis Strait, 2004–05, J. Phys. Oceanogr., 41, 429-436, doi: 10.1175/2010JPO4536.1, 2010.

Curry, B., Lee, C. M., Petrie, B., Moritz, R. E., and Kwok, R.: Multiyear Volume, Liquid Freshwater, and Sea Ice Transports through Davis Strait, 2004–10, J. Phys. Oceanogr., 44, 1244-1266, doi: 10.1175/JPO-D-13-0177.1, 2014.

Day, J. J., Hawkins, E., and Tietsche, S.: Will Arctic sea ice thickness initialization improve seasonal forecast skill? Geophys. Res. Lett., 41, 7566–7575, doi: 10.1002/2014GL061694, 2014.

Haine, T. W. N., Curry, B., Gerdes, R., Hansen, E., Karcher, M., Lee, C., Rudels, B., Spreen, G., de Steur, L., Stewart, K. D., and Woodgate, R.: Arctic freshwater export: Status, mechanisms, and prospects, Global Planet. Change, 125, 13-35, doi: 10.1016/j.gloplacha.2014.11.013, 2015.

Johnson, M., Proshutinsky, A., Aksenov, Y., Lindsay, A. T. N. R., Haas, C., Zhang, J., Diansky, N., Kwok, R., Maslowski, W, Häkkinen, S., Ashik, I., Cuevas, B.: Evaluation of Arctic sea ice thickness simulated by Arctic Ocean Model Intercomparison Project models, J. Geophys. Res-Oceans., 117, C00D13, doi: 10.1029/2011JC007257, 2012.

Kwok, R.: Baffin Bay ice drift and export: 2002–2007, Geophys. Res. Lett., 34, L19501, doi:10.1029/2007GL031204, 2007.

Kwok, R.: Variability of Nares Strait ice flux, Geophys. Res. Lett., 32, L24502, doi:10.1029/2005GL024768, 2005.

Min, C., Mu, L., Yang, Q., Ricker, R., Shi, Q., Han, B., Wu, R., and Liu, J.: Sea ice export through the Fram Strait derived from a combined model and satellite data set, The Cryosphere, 13, 3209-3224, doi: 10.5194/tc-13-3209-2019, 2019.

Mu, L., Losch, M., Yang, Q., Ricker, R., Losa, S. N., and Nerger, L.: Arctic-Wide Sea Ice Thickness Estimates from Combining Satellite Remote Sensing Data and a Dynamic Ice-Ocean Model with Data Assimilation During the CryoSat-2 Period, J. Geophys. Res-Oceans., 123, 7763-7780, doi: 10.1029/2018JC014316, 2018a.

Mu, L., Yang, Q., Losch, M., Losa, S. N., Ricker, R., Nerger, L., and Liang, X.: Improving sea ice thickness estimates by assimilating CryoSat-2 and SMOS sea ice thickness data simultaneously, Q. J. Roy. Meteor. Soc., 144, 529–538, https://doi.org/10.1002/qj.3225, 2018b.

Ricker, R., Girard-Ardhuin, F., Krumpen, T., and Lique, C.: Satellite-derived sea ice export and its impact on Arctic ice mass balance, The Cryosphere, 12, 3017-3032, doi: 10.5194/tc-12-3017-2018, 2018.

Ricker, R., Hendricks, S., Helm, V., Skourup, H., and Davidson, M.: Sensitivity of CryoSat-2 Arctic sea-ice freeboard and thickness on radar-waveform interpretation, The Cryosphere, 8, 1607-1622, doi: doi:10.5194/tc-8-1607-2014, 2014.

Ricker, R., Hendricks, S., Kaleschke, L., Tian-Kunze, X., King, J., and Haas, C.: A weekly Arctic sea-ice thickness data record from merged CryoSat-2 and SMOS satellite data, The Cryosphere, 11, 1607-1623, doi: 10.5194/tc-11-1607-2017, 2017.

Serreze, M. C., Barrett, A. P., Slater, A. G., Woodgate, R. A., Aagaard, K., Lammers, R. B., Steele, M., Moritz, R., Meredith, M., and Lee, C. M.: The large-scale freshwater cycle of the Arctic, J. Geophys. Res-Oceans., 111, C11010, doi: 10.1029/2005JC003424, 2006.

Schweiger, A., Lindsay, R., Zhang, J., Steele, M., Stern, H., and Kwok, R.: Uncertainty in modeled Arctic sea ice volume, J. Geophys. Res-Oceans., 116, C00D06, doi:10.1029/2011JC007084, 2011.

Spreen, G., de Steur, L., Divine, D., Gerland, S., Hansen, E., & Kwok, R.: Arctic sea ice volume export through Fram Strait from 1992 to 2014, J. Geophys. Res-Oceans., 125, e2019JC016039, doi: 10.1029/2019JC016039, 2020.

Tang, C. C. L., Ross, C. K., Yao, T., Petrie, B., DeTracey, B. M., and Dunlap, E.: The circulation, water masses and sea-ice of Baffin Bay, Prog. Oceanogr., 63, 183-228, doi: 10.1016/j.pocean.2004.09.005, 2004.

Tilling, R. L., Ridout, A., Shepherd, A., and Wingham, D. J.: Increased Arctic sea ice volume after anoma- lously low melting in 2013, Nat. Geosci., 8, 643–646, https://doi.org/10.1038/Ngeo2489, 2015.

Xiu, Y., Min C., Xie, J., Mu, L., Wu, X., Han, B., Yang, Q.: Evaluation of the Sea Ice Thickness in an Arctic Sea Ice-Ocean Reanalysis, J. Glaciol., in review, 2020.

Yang, Q., Losa, S. N., Losch, M., Jung, T., Nerger, L.: The role of atmospheric uncertainty in Arctic summer sea ice data assimilation and prediction, Q. J. Roy. Meteor. Soc., 141(691), 2314–2323, doi: 10.1002/qj.2523, 2015a.

Yang, Q., Losa, S. N., Losch, M., Liu, J., Zhang, Z., Nerger, L., Yang, H.: Assimilating summer sea-ice concentration into a coupled ice–ocean model using a LSEIK filter, Ann. Glaciol., 56(69), 38–44, doi: 10.3189/2015AoG69A740, 2015b.

Yang, Q., Losch, M., Losa, S. N., Jung, T., Nerger, L., Lavergne, T.: Brief communication: The challenge and benefit of using sea ice concentration satellite data products with uncertainty estimates in summer sea ice data assimilation, The Cryosphere, 10(2), 761–774, doi: 10.5194/tc-10-761-2016, 2016.

Warren, S. G., Rigor, I. G., Untersteiner, N., Radionov, V. F., Bryazgin, N. N., Aleksandrov, Y. I., and Colony, R.: Snow depth on Arctic sea ice, J. Climate, 12, 1814–1829, 1999.

Zhang, J. and Rothrock, D. A.: Modeling Global Sea Ice with a Thickness and Enthalpy Distribution Model in Generalized Curvilinear Coordinates, Mon. Wea. Rev., 131, 845-861, doi: 10.1175/1520-0493(2003)131<0845:MGSIWA>2.0.CO;2, 2003.

Responses to referee #2

General Comments:

The sea ice volume variations within the Baffin Bay is investigated using model-based sea ice thickness and NSIDC sea ice drift product. Since field measurements of sea ice thickness is scarce, this study presents the best way to estimate the sea ice in-flow/outflow of the bay. Moreover, the volume amounts in associated with freezing and melting processes are also quantified. Generally, this is a good attempt to conduct the studies related to sea ice volume, which is a better indicator, in relative to area, to interpret the current rapid climate changes.

Dear Reviewer:

We would like to thank you for the helpful comments to improve this manuscript. Following your suggestions, we calculated the correlations between NAO/AO and sea-ice volume and sea-ice volume fluxes in Baffin Bay. As suggested by another referee, we further added the locally merged SIT observations to improve the estimation of the volume fluxes. We also revised the spelling mistakes and grammatical errors.

Below, we repeat each comment and insert our replies in the text where revisions were made. All responses are in blue font for clarity.

Corresponding Author: Qinghua Yang
Email: yangqh25@mail.sysu.edu.cn

Specific comments:

Point 1: L77, ". . .in Fram Strait and obtained" to "..in Fram Strait to obtain.."

Response: We realized that it was ambiguous in the previous version. We changed this sentence to *'Additionally, CMST is successfully applied to obtain a relatively accurate estimation of the year-round sea ice volume export through the Fram Strait (Min et al., 2019).'* ***(please see P4 line 116-118 in our revised manuscript)***

Point 2: L79 "2.2…" L88 "2.3"

Response: Thanks for your conscientious review of this manuscript. We revised this in our revised manuscript.

Point 3: L101 ".. the years…" to " the short period".

Response: Following your advice, we changed this sentence to: *Since the TOPAZ4 reanalysis data cover a short period from 2014 to 2018, the TOPAZ4 SIT and SID are only used for inter-comparison with the other sea ice data but not for any volume or flux calculations in this study.* ***(please see P5 line 145-147 in our revised manuscript)***

Point 4: L110 “ … full filled…” to “… fully filled’
Response: We have changed the “… full filled” to “… fully filled”.

Point 5: L114 “date” to “data”
Response: We changed the “date” to “data”.

Point 6: L140 “ are a typical representation” to “ typically represent”
Response: Thanks for your comments. We modified this sentence: *‘We have chosen these months as they typically represent the seasonal cycle’.* ***(please see P7 line 119-200 in our revised manuscript)***

Point 7: L166 the sentence for “ A fairly … ice drift”. Make it to two short sentence in order to clarify your description.
Response: Thanks. Following your advice, we split this sentence into two short sentence: *‘A fairly similar cycle of SID is shown by CMST, TOPAZ4 and satellite-based observation. However, both CMST and TOPAZ4 present a higher ice velocity than that from satellite-based observation while NAOSIM and PIOMAS underestimate the monthly mean ice drift’.* ***(please see P8 line 230-232 in our revised manuscript)***

Point 8: L181 “Originate” to “Originates”.
Response: We modified this as suggested.

Point 9: L186-189, this sentence is too long to follow the content. I recommend the authors to make it short or by dividing it to two sentences.
Response: Thank you for this suggestion. We modified our description as follows: *Landy et al. (2017) developed a 14-year SIT data in the eastern Canadian Arctic (ECA) from ICESat, CryoSat-2 and passive microwave (PMW) snow depths, then merged with SMOS where the mean CryoSat-2 thickness is <1 m. This satellite-based data is successfully utilized to calculate the local sea ice volume variation in the Baffin Bay while the sea ice volume fluxes and thermodynamic growth are not involved (Landy et al., 2017).* ***(please see P2 line 45-49 in our revised manuscript)***

Point 10: L197, remove “, respectively”.
Response: We removed “, respectively” as suggested.

Point 11: L199 “In average” to “On average”
Response: Thanks, we have changed the “In average” to “On average”.

Point 12: L210 “invested” to “investigated”?
Response: We have modified this sentence: *In this study, the locally thermodynamic processes are further investigated by considering of sea ice freezing, melting and volume fluxes (Fig. 5).* ***(please see P10 line 289-290 in our revised manuscript)***

Point 13: L214, “in average” to “on average”

Response: We changed the "In average" to "On average".

Point 14: L224 "found" to "identified"
Response: We changed "found" to "identified" as suggested.

Point 15: L226 what "these areas" represents for? Please clarify.
Response: We changed our expression to: *We thus speculate that most of the thick ice may be exported from the Arctic since the higher ice velocity is also found in the corresponding area of the thick ice located (i.e., Nares Strait), and the faster ice is usually deemed to be a proxy for higher ice flux, which is also noticed in previous studies (Kwok, 2005, 2007).* ***(please see P10 line 306-310 in our revised manuscript)***

Point 16: L240 "with of the usage" to "with the usage".
Response: Thanks. We changed "with of the usage" to "with the usage".

Point 17: Does the author have considered the impacts of large-scale atmospheric circulation, such as NAO, on the variations of sea ice volume in Baffin Bay? The NAO may be associated with the inflow/outflow, as well as the freezing and melting processes. Therefore, through the analysis of the correlation between NAO and sea ice volume changes owing to these processes may give us a preliminary understanding of the role of the large-scale atmospheric circulation in modulating the Baffin Bay sea ice volume variations.
Response: Thank you for this constructive advice. We added an analysis on the correlation between NAO/AO and sea ice volume changes as suggested. The correlation coefficient (CC) between NAO/AO and SIV inflow and outflow for seasonal data are shown in Figure 1. The CCs between NAO and SIV inflow and outflow are 0.68 and 0.56, respectively. For AO and SIV inflow, the CCs are 0.34 and 0.42, respectively. However, we know that the long-term (climatic) time series of sea ice fluxes are required to substantiate these findings.
As suggested, we added this discussion in the discussion section. ***(please see P10 line 311-317 in our revised manuscript)***

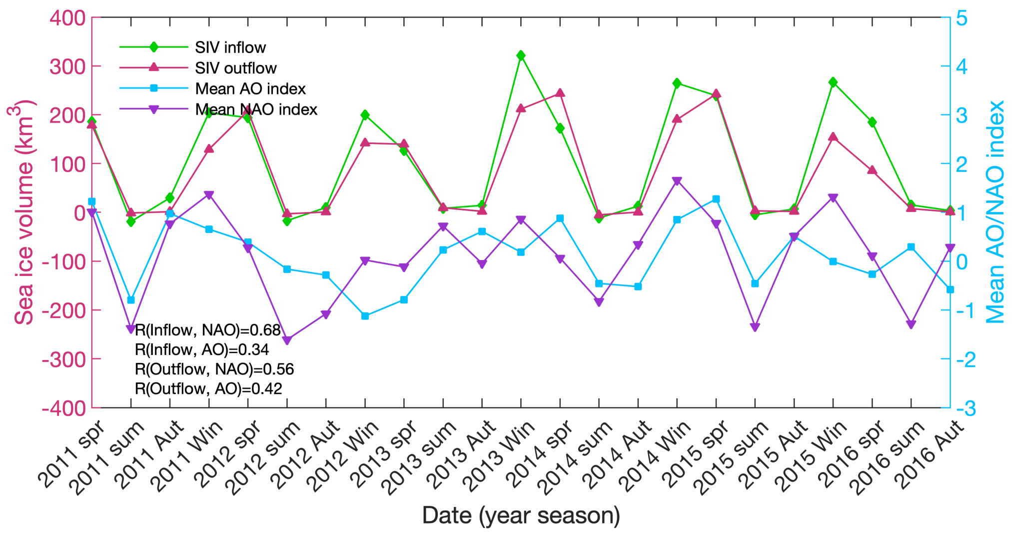


Figure 1 Time series of seasonal mean sea ice volume (SIV) inflow (green line), outflow (violet red line) in the Baffin Bay. The NAO (purple line) and AO (cyan line) indexes are averaged in the same period. R represents the correlation coefficient between NAO/AO and inflow and outflow.

Reference

Landy, J. C., Ehn, J. K., Babb, D. G., Thériault, N., and Barber, D. G.: Sea ice thickness in the Eastern Canadian Arctic: Hudson Bay Complex & Baffin Bay, Remote Sens. Environ., 200, 281-294, doi: 10.1016/j.rse.2017.08.019, 2017.

Min, C., Mu, L., Yang, Q., Ricker, R., Shi, Q., Han, B., Wu, R., and Liu, J.: Sea ice export through the Fram Strait derived from a combined model and satellite data set, The Cryosphere, 13, 3209-3224, doi: 10.5194/tc-13-3209-2019, 2019.

Ensemble-based estimation of sea-ice volume variations in the Baffin Bay

Chao Min[1,2], Qinghua Yang[1,2], Longjiang Mu[3], Frank Kauker[3,4], Robert Ricker[3]

[1]School of Atmospheric Sciences, Sun Yat-sen University, and Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai, 519082, China

[2]State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029, China

[3]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, 27570 Bremerhaven, Germany

[4]Ocean Atmosphere Systems, 20249 Hamburg, Germany

Correspondence to: Qinghua Yang (yangqh25@mail.sysu.edu.cn)

Abstract. Sea ice in the Baffin Bay plays an important role in deep water formation in the Labrador Sea and contributes to the variation of the Atlantic meridional overturning circulation (AMOC) on larger scales. Sea-ice data from locally merged satellite observations (Sat-merged SIT) in the Eastern Canadian Arctic and three state-of-the-art sea ice-ocean models are used to quantify sea-ice volume variations from 2011 to 2016. Ensemble-based sea-ice volume (SIV) fluxes in the Baffin Bay are generated from four different estimates of SIV fluxes that derived from Sat-merged SIT, three modeled SITs and satellite-based ice-drift data. Results show that the net increase of the SIV in Baffin Bay occurs from October to early April with the largest SIV increase in December (113±17 km^3 month^{-1}) followed by a reduction from May to September with the largest SIV decline in July (-160±32 km^3 month^{-1}). The maximum SIV inflow occurs in winter with the amount of 236(±38) km^3 while ice outflow reaches the maximum in spring with a mean value of 168(±46) km^3. The ensemble mean SIV inflow reaches its maximum (294±59 km^3) in winter 2013 caused by high ice velocity along the north gate while the largest SIV outflow (229±67 km^3) occurs in spring of 2014 due to the high ice velocity and thick ice along the south gate. The long-term annual mean ice volume inflow and outflow are 411(±74) km^3 and 312(±80) km^3 year^{-1}, respectively. Our analysis also reveals that on average, sea ice in the Baffin Bay melts from May to September with a net reduction of 335 km^3 in volume while it freezes from October to April with a net increase of 218 km^3. In the melting season, there is about 268 km^3 freshwater produced by local melting of sea ice in the Baffin Bay. In the annual mean, the mean freshwater converted from SIV outflow that enters the Labrador Sea is about 250 km^3 year^{-1} (i.e., 8 mSv), while it is only about 9% of the net liquid freshwater flux through the Davis Strait. The maximum freshwater flux derived from SIV outflow peaks in March with the amount of 65 km^3 (i.e., 25 mSv).

1 Introduction

Baffin Bay is a semi-enclosed basin between Ellesmere Island, Baffin Island and Greenland. This bay serves as an important pathway of southward flowing and cold freshwater draining off from the Arctic into the North Atlantic Oceans (Curry et al.,

删除了: **Multi-model…nsemble** ... [1]

删除了:

删除了: the

删除了: To quantify

删除了: the

删除了: sea ice volume variations in the Baffin Bay, a major driver of the deep water formation, a locally merged satellite …s ... [2]

删除了:

删除了: (Landy et al., 2014) …nd three state-of-the-art sea ice-ocean models (CMST, NAOSIM, and PIOMAS) ... [3]

删除了:

删除了: investigated in the melting and freezing season

删除了: An ensemble …nsemble-based of three estimates of the ... [4]

删除了:

删除了: es…in the Baffin Bay is …re generated from the ... [5]

删除了: sea ice thickness

删除了: NSIDC …atellite-based derived ... [6]

删除了:

删除了: ensemble mean sea ice volume (SIV)…IV in Baffin Bay occurs from October to early April with the largest SIV increase in December (116…13±17 ±16 ... [7]

删除了: and the …eduction occurs ... [8]

删除了: 160…60±32±32 …km^3 month^{-1}). The maximum SIV inflow occurs in winter in all the model data consistently ... [9]

设置了格式 ... [10]

删除了: (322±4 km^3) …eaches its maximum (294±59 km^3) in winter 2013 caused by high ice velocityies…along the north gate while the largest SIV outflow (244…29±61 …7 km^3) occurs in spring of 2014 due to the high ice velocity and thick ice along the south gate. The long-term annual mean ice volume inflow and outflow are 437…11(±53…4) km^3 and 339…12(±68…0) km^3 year^{-1}, respectively. Our analysis also reveals that on average, sea ice in the Baffin Bay melts from May to October…eptember with a net reduction of 335 km^3 volume while it freezes from November…ctober to April with a net increase of 251 ... [11]

删除了: that melt from …ocal melting of sea ice in the Baffin Bay. In the annual meanAnnually ... [12]

删除了: year^{-1} …i.e., 8 mSv), while it is only about 9% of the net liquid freshwater flux through the Davis Strait. The maximum freshwater flux derived from SIV outflow peaks in ... [13]

2010; Curry et al., 2014). Freshwater outflows through Davis Strait entering the Labrador Sea are integrated from Canadian Arctic Archipelago and west Greenland glacial runoff, river inputs, sea ice meltwater and precipitation (Curry et al., 2010; Curry et al., 2014; Tang et al., 2004). Locally, sea ice in Baffin Bay has a significant influence on Greenland coastal air temperatures and ice sheet surface-melt (Ballinger et al., 2018; Rennermalm et al., 2009; Stroeve et al., 2017). The sea ice condition in Baffin Bay also impacts wildlife habitations (Ferguson et al., 2000; Laidre and Heide-Jørgensen, 2004; Spencer et al., 2014). Furthermore, marine-based activities, such as shipping, are strongly influenced by the sea ice conditions in the bay (Pizzolato et al., 2016). Therefore, understanding the sea ice variations in the Baffin Bay is of strong interest for climate change research but also for stakeholders.

Landy et al. (2017) composed a 14-year SIT data set in the eastern Canadian Arctic (ECA) from ICESat, CryoSat-2 and passive microwave (PMW) snow depths, then merged with SMOS where the mean CryoSat-2 thickness is <1 m. This Sat-merged SIT data are utilized to calculate the local sea ice volume variation in the Baffin Bay but not the sea ice volume fluxes and thermodynamic growth (Landy et al., 2017). However, seasonal thin sea ice in the bay is dominating and satellite-based ice thickness has large errors in the bay with respect to other regions in the Arctic Basin. For example, SMOS SIT usually underestimates the ice thickness when the ice is thicker than 1.0 m and CryoSat-2 SIT has large uncertainties for thin ice below 1.0 m (Ricker et al., 2014; Tian-Kunze et al., 2014; Tietsche et al., 2018). In a recent study, Bi et al. (2019) analysed the sea-ice area fluxes in Baffin Bay on a long-term time period and the increasing trend of the annual sea-ice area flux are found to be 38.9 × 10^3 km^2 decade^{-1} for the inflow through the north gate, 7.5 × 10^3 km^2 decade^{-1} for the inflow through Lancaster Sound and 82.2 × 10^3 km^2 decade^{-1} for the outflow through the south gate (Davis Strait), respectively. However, sea-ice volume variations in Baffin Bay, strongly controlled by sea-ice volume inflow and outflow, are not investigated in that study. Cuny et al. (2005), Tang et al. (2004) and Kwok (2007) estimated the annual mean SIV outflow through Davis Strait into the Labrador Sea based on simple assumptions of linear variation of mean SIT across the strait due to scarce SIT observations. They reported mean SIV outflows through Davis Strait of about 528 km^3 year^{-1}, 873 km^3 year^{-1} and 530-800 km^3 year^{-1}, respectively. Until several years ago, the mean SIV outflow (407 km^3 year^{-1}, from 2004 to 2010) averaged from November to May is approximately presented with the SIT observations from five upward looking sonars (ULSs) that are moored in the Davis Strait rather than a simple SIT assumption (Curry et al., 2014). However, to the authors' knowledge, there is no study investigating the year-round SIV inflow and outflow covering the years of the lowest sea-ice extent records (i.e., 2012 and 2016). The freshwater budget is a function of sea-ice formation and melting, input from river water and land-ice input (Landy et al., 2014; Landy et al., 2017). The sea-ice thermodynamic processes are closely related to the desalination of seawater and the freshwater budget in the Baffin Bay. For instance, during sea-ice freezing, salt is discharged into the surface ocean water leading to denser and saltier conditions which destabilizes the water column. On the other hand, when the sea ice melts, fresh/hyposaline water is drained into the surface water causing desalination of the surface water and, consequently, stabilizes the water column.

In this study, we focus on the local sea-ice volume variations in Baffin Bay. We define the SIV inflow and outflow gates following Kwok (2007) to be located at ~73°N and ~68°N between Baffin Island and Greenland (Fig. 1), respectively. The

删除了:

删除了:

删除了: support

删除了: Landy et al. (2017) investigated the sea ice thickness (SIT) distribution and sea ice growth rate using satellite-based observations (e.g., SMOS, ICESat and CryoSat-2 SIT)

设置了格式: 字体颜色: 文字 1

删除了: …ce area fluxes in the …affin Bay on a long-term time period for the first time …nd the increasing trend of the annual sea …ice area flux are found to be, i.e.,…38.9 × 10^3 km^2 decade^{-1} for the inflows ... [14]

删除了: entering the bay

删除了:

删除了: s…through Lancaster Sound and 82.2 × 10^3 km^2 decade^{-1} for the outflows ... [15]

删除了: and 7.5 × 10^3 km^2 decade^{-1} for Lancaster Sound,

删除了: …ce volume variations in Baffin Bay, strongly controlled by the…sea ... [16]

删除了: ow

删除了: s

删除了: that export …through Davis Strait into the Labrador SeaBaffin Bay ... [17]

删除了: a …imple assumptions of linear variation of mean SIT across the strait due to scarce SIT observations. They reported the ... [18]

删除了: a …ean SIV outflows through Davis Strait of about 528 km^3 year^{-1}, 873 km^3 year^{-1} and 530-800 km^3 year^{-1}, respectively. Until several years ago, the mean SIV outflow (407 km^3 year^{-1}, from 2004 to 2010) averaged from November to May are …s approximately presented with the SIT observations from five upward looking sonars (ULSs) that are moored in the Davis Strait rather than a simple SIT assumption from five upward looking sonars (ULSs) that moored in the Davis Strait ... [19]

删除了: such a …tudy investigating the year-round SIV inflow and outflow covering the years of the lowest sea …ice extent records (i.e., 2012 and 2016). TIndeed, t…e freshwater budget is a function of sea …ice formation and melting, input from river water and land …ice input (Landy et al., 2014; Landy et al., 2017). The sea …ice thermodynamic processes are closely related to the desalination of seawater and the freshwater budget in the Baffin Bay. For instance, during the …ea …ice freezing, process the …alt iss …discharged into the surface ocean water leading to a …enser and saltier ... [20]

删除了: …ice volume variations in Baffin Bay. We define the SIV inflow and outflow gates following Kwok (2007) to ... [21]

sea-ice imported into Baffin Bay through the north gate can be divided into three sources: Sea ice input (including multi-year ice) from Nares Strait, Lancaster Sound and Jones Sound that originates from the Arctic Ocean and the Canadian Arctic Archipelago (CAA) and a large amount of ice generated in polynyas, i.e., the North Water (NOW) Polynya (Bi et al., 2019; Kwok, 2005, 2007). In our study, we focus on the total amount of sea-ice inflows through the north gate summing up the ice from the Arctic Ocean, the CAA and the NOW Polynya. Sea-ice volume variations are calculated in the area between the north gate and the south gate. There is limited *in-situ* observed SIT in this bay. Also, SMOS, Cryosat-2 and CS2SMOS have large uncertainties in that area (Ricker et al., 2014; Ricker et al., 2017; Tian-Kunze et al., 2014; Tietsche et al., 2018). For instance, SMOS SIT is underestimated because (1) SMOS only provides valid SIT for ice thinner than 1 m and (2) the 100% ice concentration assumption during the data retrieval is not fulfilled (Tian-Kunze et al., 2014; Tietsche et al., 2018). To address the challenging estimation of sea-ice volume variations in Baffin Bay, locally merged satellite SIT data (Landy et al. 2017, 2019, 2020) and three sea ice-ocean models driven by atmospheric reanalysis are employed, namely the sufficiently well validated combined model and satellite sea ice thickness (CMST), the widely used Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS), a version of the North Atlantic/Arctic Ocean Sea Ice Model (NAOSIM) with optimized parameters. Because very little *in-situ* observations can be used for validation in Baffin Bay, we carry out an inter-comparison between CMST, NAOSIM, PIOMAS, the Towards an Operational Prediction system of the North Atlantic and European coastal Zones (TOPAZ4) and the merged satellite SIT of Landy et al. (named Sat-merged SIT hereafter). To obtain an estimate of the sea-ice volume fluxes, we calculate the ensemble mean of the inflows and outflows from the three modeled SITs, Sat-merged SIT and satellite-based ice drift. Furthermore, since the Baffin Bay plays a crucial role as the primary source of freshwater and sea ice in the Labrador Sea (Curry et al., 2014; Tang et al., 2004), the amount of freshwater flux exported into the Labrador Sea is calculated based on the estimated outflowing SIV through the Davis Strait.

This paper is organized as follows: Sea ice data sets and computing methods used in this study are described in section 2. In section 3, we present the major findings. Discussions of SIV flux uncertainties and freshwater fluxes are given in section 4. In section 5, main findings are finally drawn.

2 Data and methods

2.1 CMST sea ice data

The complementarity of SMOS SIT and CryoSat-2 SIT is utilized in CMST by assimilating SMOS SIT from University of Hamburg, CryoSat-2 SIT from AWI and Special Sensor Microwave Imager/Sounder (SSMIS) ice concentration processed at IFREMER into the MITgcm (Mu et al., 2018a). The sea ice-ocean model is forced by ensemble atmospheric forecasts from the UK Met Office (UKMO) taking the uncertainty of the atmospheric data into account (Yang et al., 2015). CMST provides daily sea-ice thickness (SIT), concentration (SIC) and drift (SID). CMST SIT was systematically validated within the Arctic basin by Mu et al. (2018a) and its SID were further validated against NSIDC and SAR data in the Fram Strait by Min et al.

删除了: …ce imported into the …affin Bay through the north gate can be divided into three sources: Sea ice inputs…(including multi-year ice) from Nares Strait, Lancaster Sound and Jones Sound that originates from the Arctic Ocean and the Canadian Arctic Archipelago (CAA) ; …nd moreover, … large amount of ice is …enerated in recurring ... [22]

删除了: 7… 20075 ... [23]

删除了: only …ocus on the total amount of sea-ice inflows through the north gate summing up , so …he ice from the Arctic Ocean, the CAA and the NOW Polynya are summed up to derive the sea ice inflow through the north gate… Sea ... [24]

删除了: these two…he north gate and the south gates… There is limited *in-situ* observed SIT in this bay and… also …lso, the satellite-based SIT (i.e., …MOS, Cryosat-2 CS2SMOS) …have large uncertainties and are inappropriate to be used directly ... [25]

删除了: in the Baffin Bay, …MOS SIT is proved to be …nderestimated because (1) SMOS only provides the …alid SIT for ice that ... [26]

删除了: outsideout ofthe that is utilized for the Cryosat-2 SIT sea ice thickness retrieval and the W99 polynomial fit is thus maybe not reliable in this area at AWISMOS and Cryosat-2 SIT CS2SMOS oinover the

删除了: Furthermore, sea ice in the Baffin Bay is dominated by seasonal thin ice and Crysat-2 thus has large uncertainty in ... [27]

删除了: …ice volume variations in Baffin Bay, a ... [28]

删除了: I …ce thickness (CMST), the widely used Pan-Arctic Ice Ocean Modeling and Assimilation System ... [29]

删除了: to v…alidatione these SITs …in Baffin Bay, we carry out an inter-comparison of SIT …etween CMST, ... [30]

删除了: SMOS

删除了: ….Then, …oto…obtain an estimate of the sea …ice volume fluxes, we calculate the ensemble mean of the inflows ... [31]

删除了:

删除了: the

删除了: NSIDC …atellite-based ice drift, the only observed ice drift available the year round during the study period ... [32]

删除了: …ice infor…the Labrador Sea (Curry et al., 2014; Tang et al., 2004),…the amount of freshwater flux ... [33]

删除了: fluxes exported

删除了: ….Sea ice data sets and computing methods used in this study are described in section 2. In section 3, we present ... [34]

删除了: I

删除了: …ice thickness (SIT), concentration (SIC) and drift (SID). Moreover, …MST SIT wasis ... [35]

(2019). Additionally, CMST is successfully applied to obtain a relatively accurate estimation of the year-round sea ice volume export through the Fram Strait (Min et al., 2019).

2.2 NAOSIM sea ice data

The NAOSIM SIT data are produced by a regional sea ice-ocean model of the Arctic and northern North Atlantic Ocean (NAOSIM) developed at the Alfred Wegener Institute (Köberle and Gerdes, 2003; Kauker et al., 2003; Karcher et al., 2007). The model is forced by the NCEP Climate Forecast System version 2 (Saha et al. 2014). 15 model parameters (e.g., ice strength, drag coefficients) were optimized simultaneously using a micro genetic algorithm (mGA). A detailed description of NAOSIM and the methodology used for the optimization can be found in Sumata et al. (2019a, b). The model version used in this study distinguishes from the model version applied for the optimization in Sumata et al. (2019a, b) by a horizontal resolution of about 28 km (Model version MR in Sumata et al. (2019a)). The parameters (except the vertical mixing coefficient) are taken from the third optimization of Sumata et al. (2019b) termed OPT-3.

2.3 PIOMAS sea ice data

The widely used Pan-Arctic Ice-Ocean Modeling and Assimilation System (PIOMAS) SIT data are produced by a sea-ice ocean model that assimilates near-real-time daily SIC from National Snow and Ice Data Center (NSIDC) and sea surface temperature in the ice-free areas from the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) reanalysis by nudging and optimal interpolation (Schweiger et al., 2011; Zhang and Rothrock, 2003). It is forced by atmospheric data from the NCEP/NCAR reanalysis (Schweiger et al., 2011; Zhang and Rothrock, 2003). Effective sea-ice thickness data are provided operationally from 1978 on and is permanently updated. In this study, we use the monthly SIT data of PIOMAS V2.1 from 2011 to 2016.

2.4 TOPAZ4 sea ice data

TOPAZ4 is a regional ocean and sea-ice prediction system. The ocean model is based on the Hybrid Coordinate Ocean Model (HYCOM version 2.2) (Bleck, 2002; Chassignet et al., 2003). The sea-ice model employs the one-thickness category and elastic-viscous-plastic rheology (Bouillon et al., 2013; Hunke and Dukowicz, 1997). This system is forced by ERA-interim atmospheric reanalysis. Ocean and sea ice observations are assimilated into TOPAZ4 (e.g., the along track sea level anomaly and gridded sea surface temperature, OSI-SAF sea ice concentration and drift, and CS2SMOS SIT) (Xie et al., 2018). Since the TOPAZ4 reanalysis data cover a short period from 2014 to 2018, the TOPAZ4 SIT and SID are only used for inter-comparison with the other sea ice data but not for any volume or flux calculations in this study.

2.5 Sat-merged SIT data

Because in-situ observations of SIT are very scarce in Baffin Bay, a locally merged satellite SIT (Sat-merged SIT) data set is utilized to calculate the SIV variations during the freezing season since this data set are used to estimate the sea ice variations

- 删除了: successfully
- 删除了: in Fram Strait and obtained a relatively accurate estimate of the year-round sea ice volume export through Fram Strait
- 删除了: **3**
- 删除了: is
- 删除了: the
- 删除了: **4**
- 删除了: is
- 删除了: , atmospheric forcing and sea surface temperature from National Centers for Environmental Prediction (NCEP) ... [36]
- 删除了: XXX
- 删除了: Zhang and Rothrock, 2003;
- 删除了: National Center for Environmental Prediction (
- 删除了:) and National Center for Atmospheric Research (
- 删除了:)
- 删除了: (Citation)
- 删除了:
- 删除了: n
- 删除了: The
- 删除了: ,
- 删除了: s
- 删除了: the
- 删除了: only the years
- 删除了: in this study,
- 删除了: simulations
- 删除了:
- 删除了: .
- 删除了: **SMOS sea ice data**
- 删除了: **Satellite-based S**
- 删除了: A
- 删除了: The Soil Moisture and Ocean Salinity (SMOS) SIT ... [37]
- 删除了: T
- 删除了: locally
- 删除了: (named Sat-merged SIT hereafter) are
- 删除了: as observation
- 删除了: successfully

in the Eastern Canadian Arctic including Baffin Bay before. This Sat-merged SIT data are calculated from CryoSat-2 radar freeboards (accessed from the European Space Agency) and passive microwave (PMW) snow depths (available from NSIDC at https://nsidc.org/data/NSIDC-0032/versions/2) and then merged with SMOS SIT (available from the University of Hamburg at https://icdc.cen.uni-hamburg.de/en/l3c-smos-sit.html) where the mean CryoSat-2 thickness is <1 m. More details about this data set can be found in Landy et al. (2017, 2019, 2020).

2.6 NSIDC SID data

The Polar Pathfinder Daily 25 km EASE-Grid sea ice drift data (V4) from NSIDC are used to calculate SIV fluxes because it contains year-round data for the time period investigated. The AVHRR, AMSR-E, SMMR, SSM/I, SSMIS, International Arctic Buoy Program (IABP) buoys observations and reanalysis wind data are integrated to derive the NSIDC sea ice motion (Tschudi et al., 2019; Tschudi et al., 2020). The NSIDC data set has been recently validated with high-resolution Envisat wide-swath SAR observations and IABP buoy measurements by Bi et al. (2019). Comparing with the observed sea ice drift that retrieved from high-resolution (~100 m) Envisat Synthetic Aperture Radar (SAR) observations, the NSIDC drift slightly underestimates the ice drift with a mean bias of -0.68 km day^{-1}, while it has a high correlation (R=0.87) with SAR drift (Bi et al., 2019). The NSIDC drift data (V4) are chosen as a reference to evaluate model ice drift and are applied to calculate the sea-ice flux.

2.7 Retrieving methods for SIV flux

We use monthly mean sea-ice thickness and drift to obtain the SIV fluxes following Ricker et al. (2018). The formulas to derive the SIV inflows and outflows are the same as applied in Min et al. (2019):

$$Q_{flux} = L\,H\,v, \tag{1}$$

where Q_{flux} represents the SIV fluxes at the north and south gates. L and H are zonally interpolated grid width and corresponding SIT along the two gates, respectively. The meridional velocity v is utilized to estimate the sea ice flux (inflows and outflows). The SIC is not involved in equations (1), because they are already used to calculate the effective thickness in CMST, NAOSIM and PIOMAS. It is difficult to identify the most accurate SIT simulation and ice flux estimate, so we adopt the ensemble approach to estimate the sea-ice variations in the Baffin Bay, i.e., ensemble mean inflows and outflows are from (1) CMST SIT and NSIDC SID, (2) NAOSIM SIT and NSIDC SID, (3) PIOMAS SIT and NSIDC SID, and (4) Sat-merged SIT and NSIDC SID (equation (1)). And we use one standard deviation (i.e., +/-number) among these ensemble members to show the uncertainties of flux estimates in this study. Analogously, the sea-ice volume in the Baffin Bay is calculated from the ensemble mean of the Sat-merged SIT, CMST, NAOSIM and PIOMAS SIT.

Following Ricker et al. (2018), the sea ice volume variation can be derived as follows:

$$\frac{dV}{dt} = Q_{net} + \left(\frac{dV_{therm}}{dt} + \frac{dV_{resid}}{dt}\right), \tag{2}$$

删除了: , and furthermore in-situ observed SIT data are very scarce in Baffin Bay… This Sat-merged SIT data are calculated from CryoSat-2 radar freeboards (accessed from the European Space Agency) and passive microwave (PMW) snow depths (available from NSIDC at https://nsidc.org/data/NSIDC-0032/versions/2) and,…then merged with SMOS SIT (available from the University of Hamburg at https://icdc.cen.uni-hamburg.de/en/l3c-smos-sit.html) where the mean CryoSat-2 thickness is <1 m (Landy et al., 2017, 2019, 2020)… More details about this data set be found in previous studies (…andy et al.(, ... [38]

删除了: he SMOS SIT observations are utilized because *in-situ* observed SIT data are very scarce in Baffin Bay, and the Crysat-2/CS2SMOS SIT data are inappropriate in this area with strong seasonality (Ricker et al., 2014; Ricker et al., 2017). We should keep in mind that the SMOS SIT data underestimate the SIT in the Baffin Bay mainly because the 100% ice concentration assumption during the data retrieval is not full filed (Tian-Kunze et al., 2014; Tietsche et al., 2018).

删除了: **NSIDC**

删除了: e…for the time period investigated. The AVHRR, AMSR-E, SMMR, SSM/I, SSMISSSM/I… International Arctic Buoy Program (IABP) buoys observations and reanalysis wind data are integrated to derive the NSIDC sea ... [39]

删除了: then…applied to calculate the sea ... [40]

删除了: , since they cover the time span from 2011 to 2016 ... [41]

删除了: **in**

删除了:

删除了: Meier et al. (2006) and

设置了格式 ... [42]

设置了格式 ... [43]

删除了: also…utilized to estimate the sea ice flux (inflows ... [44]

删除了: ion… so we adopt the ensemble approach to ... [45]

删除了: . -

删除了:

删除了: NSIDC SID… (2) NAOSIM SIT and . - ... [46]

删除了:

删除了: NSIDC SID… (3) PIOMAS SIT and . - ... [47]

删除了:

删除了: NSIDC SID… and (4) Sat-merged SIT and .- ... [48]

删除了:

删除了: and Bi et al. (2019)

设置了格式 ... [49]

where dV/dt represents the monthly SIV change in the Baffin Bay. Q_{net} is the monthly net SIV flux (Δflux) estimated by the difference between inflow and outflow. As suggested by Ricker et al. (2018) quantifying thermodynamic growth (dVtherm/dt) and residual contributions (dVresid/dt) due to dynamics and deformation is challenging. Therefore, we only consider their integral contribution. Eventually, the integral contribution of dVtherm/dt and dVresid/dt is regarded as thermodynamic SIV growth rate in this study. To distinguish ice melting and freezing, we use negative thermodynamic SIV growth rates to represent reduction through ice melting and positive rates to denote growth due to freezing.

3 Results

The spatial distributions of the ensemble mean SIC, SIT and SID in March, July and October are shown in Fig. 1. We have chosen these months as they typically represent the seasonal cycle. As found by Meier et al. (2006), the maximum extent occurs in March while July is the last month when sea ice is still left and the ice freeze-up starts in October. Furthermore, we present the spatial distribution of SIT especially in July when satellite-based SIT is not available due to melting processes. The ensemble mean SIT shows that the thicker ice (>1.2 m) is located east of Baffin Island in March while largest ice velocities are found near the south gate. The spatial distribution of ensemble mean SIT in March is similar to that found by Landy et al. (2017). In July sea ice thicker than 0.3 m is located near the eastern coast of Baffin Island. Focusing on the freeze-up period (October), we found ice located near the Nares Strait mostly being thicker than 0.5 m. Highest ice velocity (more than 10 km day^{-1}) is found near Smith Sound and Lancaster Sound by CMST (figure not shown).

The comparisons of SIT (averaged along the north and south gates) between CMST, NAOSIM, PIOMAS, TOPAZ4 and Sat-merged SIT are shown in Fig. 2a and 2b, respectively. The SIDs from CMST, NAOSIM, PIOMAS, TOPAZ4 and NSIDC SID are compared with each other as well (Fig. 2c and 2d). The SIC variation is not shown here because the models (except NAOSIM) have already taken SIC into account via the assimilation. In general, these sea ice properties show a significant annual cycle with the mean SIT thinner than 1 m for both the north and the south gates. Compared with the Sat-merged SIT, all simulations present thicker ice than Sat-merged SIT (Fig. 2a and 2b). The mean SIT averaged along the north gate is 0.72 m for CMST, 0.83 m for NAOSIM, 0.84 m for PIOMAS and 0.55 m for TOPAZ4 during the freezing season while the mean SIT is 0.56 m for Sat-merged SIT. Likewise, the mean SIT averaged along the south gate is only 0.40 m for Sat-merged SIT, while the mean SITs of CMST, NAOSIM, PIOMAS and TOPAZ4 are 0.52 m, 0.61 m, 0.72 m, and 0.44 m, respectively. In general, the simulations of NAOSIM and PIOMAS show thicker sea ice than the simulations of CMST and TOPAZ4 data who assimilate satellite-observed SIT. The SIT cycles of CMST and TOPAZ4 are more consistent with Sat-merged SIT as well. Furthermore, sea ice drift (SID) is an important contributor for sea ice flux variation on its monthly scale (Min et al., 2019; Ricker et al., 2018). For this reason, an accurate simulation of SID is another vital factor to derive sea-ice volume flux. Again, because of the all-year round coverage and the recent validation of NSIDC drift in the Baffin Bay by Bi et al. (2019), we apply NSIDC drift to calculate the sea ice flux in this study. In addition, we conduct an inter-comparison of SID between NSIDC SID, CMST, NAOSIM, PIOMAS and TOPAZ4 SID in Fig. 2c and 2d to examine the performance of these modeled SID data.

设置了格式 ... [50]

删除了: (i.e., ice inflow minus outflow)

删除了: Robert

删除了: ,…quantifying thermodynamic growth (dVtherm/dt) and residual contributions (dVresid/dt) , …ue to dynamics and deformation, ... [51]

删除了: We have chosen these months as they typically represent

删除了: are a typical representation for

删除了: the seasonal cycle.

删除了: suggested in

删除了: reported that

删除了: ,

删除了: variation…of SIT especially in July when satellite-based SIT is not available due to melting processes. The ensemble mean SIT shows that the thicker ice (>1.2 m) is located east of Baffin Island in March while largest ice velocities are found near the south gate in March ... [52]

删除了: in…Landy et al. (2017). In July Similarly, the …ea ice that …hicker than 0.3 m is located near the eastern coast Baffin Island in the Baffin Bay in July… When f…ocusing on the freeze-up period (October), we found the …ce located near the Nares Strait mostly beingis mostly…thicker than 0.5 m,… Highest and higher …ce velocity (more than 10 km day^{-1}) is also …ound near the ... [53]

删除了: SMOS …at-merged SIT is …re shown in Fig. 2a and 2b, respectively. The sea ice drift…IDs from CMST, NAOSIM, PIOMAS, TOPAZ4 and NSIDC …SIDC SID are …compared with each other as well (Fig. 2c and 2d). The SIC variation is not shown here because the models (except ... [54]

删除了:

删除了: satellite-observed SMOS SIT

删除了: of these SIT …imulations present thicker ice ... [55]

删除了: SMOS

删除了: …Fig. 2a and 2b). Specifically, t ... [56]

删除了: only …0.56 m for Sat-merged SIT0.47 m for ... [57]

删除了: addition… the SIT …imulations ... [58]

删除了: trends

删除了:

删除了: SMOS… Furthermore, sea ice drift (SID) is an ... [59]

删除了:

删除了: WAgain, wdisarebecause of the all-year round ... [60]

Note that the TOPAZ4 values are from 2014-2016 for the overlapping period. A fairly similar cycle of SID is shown by CMST, TOPAZ4 and NSIDC SID. However, both CMST and TOPAZ4 present higher ice velocity than NSIDC SID while NAOSIM and PIOMAS underestimate the monthly mean ice drift. Moreover, TOPAZ4 simulates the fastest ice velocity among five data sets while PIOMAS shows the lowest ice drift across the north gate. We calculate the correlation coefficients (CCs) between these model simulations and the reference NSIDC SID. The highest significant (α=0.05) CCs (0.94 and 0.92) are found between TOPAZ4 and NSIDC SID while it overestimates the ice drift compared to NSIDC SID by around 52% and 82% along the north gate and south gates, respectively. Also CMST shows high CCs compared with NSIDC SID in both two gates; the correlations are 0.90 (significant) along the north gate and 0.91 (significant) along the south gate with an overestimation of 40% and 70%, respectively. The ice drift produced by NAOSIM and PIOMAS show relatively low CCs against NSIDC SID. As an example, the CCs between NAOSIM and NSIDC SID drift are 0.61 (non-significant) and 0.61 (non-significant) along the north and south gates, respectively. The coefficients between PIOMAS and NSIDC SID are also relatively low as it is only 0.60 (significant) for the north gate and 0.71 (non-significant) for the south gate, respectively. Although CMST and NSIDC SID correlate very well over the time span from 2011 to 2016, this modeled SID shows a large overestimation of ice drift. Therefore, we conclude that modeled SID shows large uncertainties and we calculate ice flux estimates from CMST, NAOSIM, PIOMAS and a Sat-merged SIT and NSIDC SID, i.e. without using of any modeled ice drift.

The monthly and seasonal mean ice inflows and outflows from 2011 to 2016 are shown in Fig. 3 and 4, respectively. The sea-ice volume (SIV) fluxes calculated by the four members show a relatively good consistency over the years considered (Fig. 3 and 4). The ensemble mean SIV inflow and outflow are 411(±74) km³ and 312(±80) km³ per year, respectively. Even though there are some discrepancies between these four fluxes calculated from the different models and Sat-merged SIT, the fluxes show a consistent cycle of seasonal variation (in term of the ensemble standard deviation). In general, the maximum of ensemble mean ice inflows occur in February and March (82±12 km³ month⁻¹ and 82±16 km³ month⁻¹, respectively), and the ice outflow reaches its maximum in March with an ensemble mean flux of 80±21 km³ month⁻¹. Here, we define spring as the time span from March to May, summer from June to August, autumn from September to November, and winter from December to February. Seasonal sea-ice inflows and outflows from the three models show better consistency in the inflows than outflows, which we attribute to the larger discrepancies of the ice thickness along the south gate between CMST, PIOMAS and NAOSIM. On average, the maximum of ice inflow occurs in winter with a mean value of 236(±38) km³ while usually the ice outflow reaches the maximum in spring with a mean value of 168 (±46) km³. Looking into specific years, the maximum of SIV inflow (294±59 km³) occurs in winter 2013 because of the largest sea ice drift although the ice thickness is not at its maximum. The SIV inflow in the melting season (May-September) is only 9% of that in the freezing season (October–April) and the SIV outflow in the melting season only accounts for 11% of that in the freezing season. Furthermore, to quantify the freshwater imported into the Labrador Sea, an important area of deep water formation, we convert the SIV fluxes to the freshwater fluxes according to Spreen et al. (2020):

$$\left(1-\frac{S_{ice}}{S_{ref}}\right)\left(\frac{\rho_{ice}}{\rho_{water}}\right) \approx 0.8 \qquad (3)$$

删除了: ed…period. A fairly similar cycle of SID is shown ... [61]
删除了: -. …SIDC SID while NAOSIM and PIOMAS ... [62]
删除了: also
删除了: also …igh CCs compared with . -…SIDC ... [63]
删除了: ,
删除了: 90 …0 (significant) along the north gate and ... [64]
删除了: is with …arge uncertainties and we calculate ice ... [65]
删除了: . -…SIDC SIDNSIDC drift ... [66]
删除了: the usage
删除了: The sea ice imported into the Baffin Bay through ... [67]
删除了:
删除了: data sets
删除了: (mentioned in methodology section 2.7)
删除了: s
删除了: between 2011 and 2016…(Fig. 3 and 4). TIn total ... [68]
删除了: 437…11(±53…4) km³ and 339…12(±68 ... [69]
删除了: parities
删除了: three
删除了: (CMST, NAOSIM and PIOMAS)… these ... [70]
删除了: trend of …easonal variation (in term of the ... [71]
删除了: the
删除了: …ensemble mean flux of 80±21 km³ month⁻¹ ... [72]
删除了:
删除了: In
删除了: s
删除了: 251…36(±12 ... [73]
删除了: s…usually ... [74]
删除了: spring/winter…pring with a mean value of ... [75]
删除了: T
删除了: 322…94±4 ... [76]
删除了: even if the
删除了: 8…% of that in the freezing season (October–April ... [77]
删除了: where it is
删除了: sea ice volume…IV outflows …luxes to the fresh ... [78]
删除了: by multiplying a factor
删除了: of
删除了: (…preen et al. (, ... [79]
设置了格式 ... [80]
设置了格式 ... [81]
删除了: ————

where the sea ice salinity (S_{ice}) is assumed to be 4 psu, the reference seawater salinity S_{ref} is 34.8 psu, sea ice density (ρ_{ice}) is 901.3 kg m^{-3} and seawater density (ρ_{water}) is 1023.9 kg m^{-3} (Haine et al., 2015; Serreze et al., 2006). The monthly mean freshwater fluxes are shown in Table 1. The annual mean amount of freshwater flux that exported into the Labrador Sea derived from SIV flux is about 250 km^3 year^{-1} (i.e., 8 mSv). Relatively large freshwater fluxes are found from February to April peaking at 65 km^3 month^{-1} (i.e., 25 mSv) in March. The annual mean freshwater directly derived from ice meltwater in previous studies is in a range from 10 mSv (i.e., 331 km^3 year^{-1} of SIV; Curry et al., 2014) to 21.3 mSv (i.e., 873 km^3 year^{-1} of SIV; Tang et al., 2004) which is larger than our estimation.

It is essential to quantify the sea ice volume variations in the Baffin Bay because the desalination of seawater and the freshwater budget are affected by the sea ice thermodynamic processes. In this study, the locally thermodynamic processes are further investigated by considering of sea ice freezing, melting and volume fluxes (Fig. 5). The ensemble mean SIV in the Baffin Bay increases from October to early April with a maximum rate of 113±17 km^3 month^{-1} in December. It decreases from May to September with a maximum reduction rate of -160±32 km^3 month^{-1} in July. The net ice volume flux exported into the Baffin Bay occurs from October to March with a maximum of 46±7 km^3 month^{-1} in December. Moreover, we analyze the thermodynamic SIV growth rate that is divided into net ice freezing and melting growth in Fig. 5b. On average, we find that the ice freezes from October to April with a mean ice freezing rate of 31 km^3 month^{-1} while the maximum freezing rate occurs in December (67 km^3 month^{-1}). The ice melting occurs from May to September with a monthly mean of -67 km^3 month^{-1} while the maximum occurs in July (-160 km^3 month^{-1}). Taking these thermodynamic SIV growth into account, we could infer that the surface seawater salinity increases from October to April and decreases from May to September with respect to the close connection between sea ice formation/melting and the freshwater budget.

4 Discussions

The sea ice flowing into the Baffin Bay through the north gate is mainly from Nares Strait, Lancaster Sound, Jones Sound, and recurring polynyas, i.e., the North Water (NOW) Polynya (Bi et al, 2019; Kwok, 2007, 2005). Kwok (2005 and 2007) pointed out that the SIV export from the Arctic through the Robeson Channel becomes most active after July. We notice that the ice thicker than 0.5 m is mostly located near the Nares Strait in October companying with higher ice velocity (more than 10 km day^{-1}) identified near the Smith Sound and Lancaster Sound by CMST (figure not shown). We thus speculate that most of the thick ice may be exported from the Arctic since the higher ice velocity is also found in the corresponding area of the thick ice located (i.e., Nares Strait), and the faster ice is usually deemed to be a proxy for higher ice flux, which is also noticed in previous studies (Kwok, 2005, 2007). Moreover, the sea ice motion which greatly affects the SIV fluxes may be affected by the large-scale atmospheric circulation, such as NAO and AO. So we investigated the correlation coefficients (CCs) between NAO/AO (http://www.cpc.ncep.noaa.gov, last access: 01 October 2020) and SIV inflow and outflow for the seasonal cycle (shown in Fig. 7). The CCs between NAO index and SIV inflow and outflow are 0.68 and 0.56, respectively. For AO index

删除了: 0.8 following Spreen et al. (2020)

删除了:

设置了格式 ... [82]

删除了:

设置了格式 ... [83]

设置了格式 ... [84]

删除了:

设置了格式 ... [85]

删除了:) is 1023.9 kg m^{-3} (Haine et al., 2015; Serreze et al., 2006). The monthly mean fresh water…reshwater fluxes are shown in Table 1. Annually, t…he annual mean amount of freshwater…reshwater flux that exported into the Labrador Sea derived from sea ice volume…IV flux is bout …bout 2271 …0 km^3 year^{-1} (i.e., 8 mSv). Relatively large fresh water…reshwater fluxes are found from January…ebruary to April peaking at 71 ... [86]

删除了: (Landy et al., 2014; Landy et al., 2017)… In this study, The …he locally thermodynamic processes are further investigatedinvested ... [87]

删除了: with the …onsideringation ... [88]

删除了: c

删除了: onsidering …ea ice freezing and … melting …nd volume fluxes (Fig. 5). The ensemble mean SIV in the Baffin Bay increases from October to early April with a maximum rate of …f 113±17 km^3 month^{-1} 116±16 km3 month-1… in December. It decreases from May to September with a maximum reduction rate of -160±3232…km^3 month^{-1} in July. Consistently, t…he net ice volume flux exported into the Baffin Bay occurs from October to January…arch with a maximum of 47…6±78…km^3 month^{-1} in December. Moreover, we analyze the thermodynamic SIV growth rate that is divided into net ice freezing and melting growth in Fig. 5b. In …n average, we find that the ice freezes from November…ctober to April with a mean ice freezing rate of ... [89]

删除了: …iscussions ... [90]

删除了: imported into the

删除了: 7…and 20075… pointed out that the SIV export from the Arctic through the Robeson Channel becomes most ... [91]

删除了: found …ear the Smith Sound and Lancaster Sound by CMST (figure not shown). We thus speculate that most of ... [92]

删除了: i

删除了: n these areas,

删除了: . This…is also noticed in previous studies (Kwok, 20057… 20075 ... [93]

删除了: preliminarily

and SIV inflow and outflow, the CCs are 0.34 and 0.42, respectively. However, long-term (climatic) time series of NAO/AO and sea ice fluxes are certainly required to obtain reliable linkages.

Sea ice freezing and melting processes in Baffin Bay and SIV fluxes exported through the Davis Strait are important for the deep water formation in the Labrador Sea. The annual mean sea ice growth rate in our study is 52 km^3 month^{-1} while it is about 87 km^3 month^{-1} estimated in a previous study (Table 3, Landy et al., 2017). Also, the monthly mean SIV variability in our study is smaller than that of Landy et al. (2017) which can be attributed to a different area of the study regions. We also notice that the maximum of the SIV occurs in March or early April and that the period nearly coincides with the sea ice extent evolution reported by Meier et al. (2006) who found a maximum in March. We converted the monthly mean sea-ice inflow and outflow as well as the net flux and the ice growth/melting into the freshwater volume fluxes (Fig. 8). It should be noted that the meltwater (from ice melting in the bay) released into Baffin Bay reached its maximum of 156 km^3 month^{-1} (i.e., 59 mSv) in July of 2015 while the maximal rate of sea-ice production happened in January of 2015 leading about 65 km^3 freshwater stored in sea ice. The maximum amount of freshwater stored in sea ice in Baffin Bay is about 240 km^3 in March/April. However, it is estimated by Landy et al. (2017) to be maximal in April (445 km^3). Because the area of our defined region is only about half of that in Landy et al. (2017), the smaller estimated freshwater storage may mostly attribute to the smaller study area. The maxima of freshwater inflow and outflow take place in the period of January to March and February to April, respectively. The maximum net freshwater flux entering the Baffin Bay is about 53 km^3 month^{-1} (i.e., 20 mSv) in December of 2014 while the maximum of freshwater flux derived from ice inflow and outflow are about 99 km^3 month^{-1} (i.e., 38 mSv) in February of 2014 and 89 km^3 month^{-1} (i.e., 34 mSv) in March of 2015, respectively. The annual freshwater flux through the Davis Strait ranges from 172 km^3 (i.e., 5 mSv) in 2016 to 326 km^3 (i.e., 10 mSv) in 2015. Annually, the mean freshwater flux derived from SIV outflow is about 250 km^3 year^{-1} (i.e., 8 mSv) which is about 9% of the net liquid freshwater flux (93 mSv, Curry et al., 2014) through the Davis Strait. Moreover, the mean freshwater flux estimated in this study is slightly smaller than the estimation based on ULS SIT observations (10 mSv; Curry et al., 2014). The small difference in the estimates indicates that our ensemble-based SIV fluxes seem to be reasonable and provide a novel approach to estimate the long-term SIV variation in Baffin Bay, an area with scarce SIT *in-situ* observations.

Because of the very limited *in-situ* SIT observations in the Baffin Bay, it is not possible to identify very accurately sea-ice volume and fluxes in this area. The aim of this study is to give a state-of-the-art ensemble mean estimation of SIV flux based on a combination of model results and observations, and to conduct a first estimate of the thermodynamic growth of sea-ice volume. Additionally, this is the first study using the Sat-merged SIT and three different model outputs to estimate sea-ice variations in the Baffin Bay. We may underestimate the ice fluxes in this bay by using the NSIDC drift pointing to the fact that long-term and high-resolution sea-ice drift data in the bay still needs to be further developed. We also notice that there are some discrepancies among Sat-merged SIT, CMST, PIOMAS and NAOSIM thicknesses. For instance, the sea ice reduction period of NAOSIM and PIOMAS start later than that of Sat-merged SIT and CMST in Baffin Bay (Fig. 6) which might be connected to the assimilation of CryoSat-2 and SMOS thickness observations in CMST while PIOMAS and NAOSIM do not. CMST SIT also shows a much more coherent ice thickness to the satellite observations, e.g., the sea ice volume variation

删除了： However, we know that the l… long-term (climatic) time series of NAO/AO and sea ice fluxes are certainly required to obtain the ... [94]
删除了： .
删除了： statistical CC
删除了： significant
删除了： Landy et al. (2017) investigated the sea ice variation rate within the scope of the variability in total ice ... [95]
删除了： of ice increasement
删除了： d that …hat the maximum of the SIV occurs in ... [96]
删除了： Then,
删除了： April.
删除了： w… converted the monthly mean sea …ice inflow ... [97]
设置了格式 ... [98]
删除了： volume…of freshwater that …tored in sea ice in the ... [99]
删除了： ,
删除了： with a maximum of …45 km^3 …in April by Landy ... [100]
删除了： al
删除了： into
删除了： that
删除了： (10 mSv; Curry et al., 2014) …ased on ULS SIT ... [101]
设置了格式 ... [102]
删除了： It should be noted that, b…cause of the very limited ... [103]
删除了： . But a series of detailed validations of CMST, ... [104]
删除了： …ice volume. Additionally, this is the first study ... [105]
删除了： sea ice data model data that assimilate both SIC and ... [106]
删除了： W
删除了： w
删除了： e…maypotentially may ... [107]
删除了： the Baffin B
删除了： with
删除了： of
删除了： the usage of …SIDC drift pointing to the fact that ... [108]
删除了： 6
删除了： . For this difference, the current clue we know is ... [109]
删除了： ,
删除了： while NAOSIM and PIOMAS not

shown by CMST reaches its maximum in March (Fig. 6) which is also found by Landy et al. (2017). However, the monthly mean variability shows a consistent start (October) of ice volume growth by all of the models and Sat-merged SIT. Moreover, all of these simulations reach their maximum SIV increase and decline in December and July, respectively. Compared to the model data without SIT assimilation (NAOSIM and PIOMAS), CMST and TOPAZ4 have more similar variability to Sat-merged SIT (shown in Fig. 1a and 1b). Nevertheless, it is impossible to identify the most accurate sea-ice simulation in this area due to the lag of *in-situ* observations.

5 Conclusions

In order to examine the sea ice volume variations in the Baffin Bay, we calculated the ensemble mean SIV fluxes and thermodynamic SIV growth from Sat-merged SIT and multi-model thickness data and NSIDC SID. Main conclusions can be summarized as follows:

(1) The sea ice volume (SIV) reaches its maximum in March or early April. It starts to increase from October until the onset of the melting season. The reduction occurs from May to September. The averaged maximum growth rate of 113±17 km^3 $month^{-1}$ is found in December, while the maximum reduction rate of -160±32 km^3 $month^{-1}$ is in July.

(2) The annual mean SIV inflow and outflow are 411(±74) km^3 and 312(±80) km^3 $year^{-1}$, respectively. The SIV inflow in the melting season is only 9% of that in the freezing season. The SIV outflow in the melting season is a small fraction (11%) of the outflow in the freezing season.

(3) The maximum SIV freezing growth rate (67 km^3 $month^{-1}$) occurs in December while the maximum melting reduction rate (-160 km^3 $month^{-1}$) happens in July. On average, ice freezing (218 km^3) takes place from October to April while the ice melting (-335 km^3) occurs from May to September indicating that the surface seawater salinity may increase from October to April and decrease from May to September, correspondingly.

(4) The freshwater flux imported into the Labrador Sea derived from the sea-ice volume flux is about 250 km^3 $year^{-1}$ (i.e., 8 mSv) and large freshwater fluxes are found from February to April. The maximal freshwater flux is about 65 km^3 $month^{-1}$ (i.e., 25 mSv) and occurs in March.

Data availability. The CMST sea ice thickness and drift data can be download from https://doi.org/10.1594/PANGAEA.891475 (Mu et al., 2018b) and https://doi.org/10.1594/PANGAEA.906973 (Mu et al., 2019), respectively. The Polar Pathfinder Daily 25km EASE-Grid sea ice drift data are released by the National Snow and Ice Data Center (NSIDC, https://nsidc.org/data/nsidc-0116/versions/4, Tschudi et al., 2019; Tschudi et al., 2020). The PIOMAS sea ice thickness data are available at http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/data/model_grid (Zhang and Rothrock, 2003). The TOPAZ4 sea ice data are available at http://marine.copernicus.eu (Xie et al., 2018). The locally merged satellite sea ice data (Sat-merged SIT) can be obtained by connecting Jack C. Landy from University of Bristol.

删除了: 6
删除了: SMOS
删除了:
删除了: However
删除了: the
删除了:
删除了: which is most accurate
删除了: without
删除了: We thus applied an ensemble approach to give [110]
删除了: NSIDC ice driftsatellite-based
删除了: Sat.
删除了: April
删除了: he melt
删除了:
删除了: while t
删除了: 116±16 km3 month-1
删除了: 437(±53) km3 year-1and 339(±68) km3
删除了: 8
删除了: 10
删除了: The maxima of ice inflows occur in winter.
删除了: 70
删除了: 160
删除了: In
删除了: 251
删除了: November
删除了: 355
删除了: October
删除了: November
删除了: October
删除了: that
删除了:
删除了: 271 km^3 $year^{-1}$ and happens it is mainly from [111]
删除了: peaking rate of
删除了: 71
删除了: We thus infer that the surface seawater will be [112]
删除了: The SMOS data is available at https://icdc.cen.uni [113]
删除了: The locally merged satellite sea ice data (Sat- [114]

Author contributions. QY conceptualized this study. CM carried out these estimations and wrote the paper. FF provided the NAOSIM sea ice data. All co-authors assisted during the writing process and critically discussed the contents.

删除了: CM and

Competing interests. The Authors declare that they have no conflict of interests.

Acknowledgement. This is a contribution to the Year of Polar Prediction (YOPP), a flagship activity of the Polar Prediction Project (PPP), initiated by the World Weather Research Programme (WWRP) of the World Meteorological Organization (WMO). We acknowledge the WMO WWRP for its role in coordinating this international research activity. We thank the editor David Schroeder, referee Jack C. Landy and another anonymous referee for their constructive comments to improve the manuscript. Great gratitude is given to Jack C. Landy and Isolde Glissenaar from University of Bristol for processing the satellite-based sea ice data in the Baffin Bay and Jiping Xie from Nansen Environmental and Remote Sensing Center for providing the TOPAZ4 SIT data. Thanks are also given to Yongwu Xiu and Qian Shi from Sun Yat-sen University for their help of data processing.

设置了格式: 字体颜色: 红色

Financial support. This study is supported by the National Natural Science Foundation of China (No. 41922044, 41941009, 41676185), the Guangdong Basic and Applied Basic Research Foundation (No. 2020B1515020025), the Fundamental Research Funds for the Central Universities (No. 19lgzd07).

删除了: and Innovation and Development Program for Outstanding Graduate Students of Sun Yat-sen University

References

Ballinger, T. J., Hanna, E., Hall, R. J., Miller, J., Ribergaard, M. H., and Høyer, J. L.: Greenland coastal air temperatures linked to Baffin Bay and Greenland Sea ice conditions during autumn through regional blocking patterns, Clim. Dyn., 50, 83-100, doi: 10.1016/j.dsr.2004.10.006, 2018.

Bi, H., Zhang, Z., Wang, Y., Xu, X., Liang, Y., Huang, J., Liu, Y., and Fu, M.: Baffin Bay sea ice inflow and outflow: 1978–1979 to 2016–2017, The Cryosphere, 13, 1025-1042, doi: 10.5194/tc-13-1025-2019, 2019.

Bleck, R.: An oceanic general circulation model framed in hybrid isopycnic-Cartesian coordinates, Ocean Model., 4, 55-88, doi: 10.1016/S1463-5003(01)00012-9, 2002.

Bouillon, S., Fichefet, T., Legat, V., and Madec, G.: The elastic-viscous-plastic method revisited, Ocean Model., 71, 2-12, doi: 10.1016/j.ocemod.2013.05.013, 2013.

Chassignet, E. P., Smith, L. T., Halliwell, G. R., and Bleck, R.: North Atlantic Simulations with the Hybrid Coordinate Ocean Model (HYCOM): Impact of the Vertical Coordinate Choice, Reference Pressure, and Thermobaricity, J. Phys. Oceanogr., 33, 2504-2526, doi: 10.1175/1520-0485(2003)033<2504:NASWTH>2.0.CO;2, 2003.

Cuny, J., Rhines, P. B., and Kwok, R.: Davis Strait volume, freshwater and heat fluxes, Deep Sea Res. P. I., 52, 519-542, doi: 10.1016/j.dsr.2004.10.006, 2005.

Curry, B., Lee, C. M., and Petrie, B.: Volume, Freshwater, and Heat Fluxes through Davis Strait, 2004–05, J. Phys. Oceanogr., 41, 429-436, doi: 10.1175/2010JPO4536.1, 2010.

Curry, B., Lee, C. M., Petrie, B., Moritz, R. E., and Kwok, R.: Multiyear Volume, Liquid Freshwater, and Sea Ice Transports through Davis Strait, 2004–10, J. Phys. Oceanogr., 44, 1244-1266, doi: 10.1175/JPO-D-13-0177.1, 2014.

Ferguson, S. H., Taylor, M. K., and Messier, F.: Influence of sea ice dynamics on habitat selection by polar bears, Ecology, 81, 761-772, doi: 10.2307/177375, 2000.

Haine, T. W. N., Curry, B., Gerdes, R., Hansen, E., Karcher, M., Lee, C., Rudels, B., Spreen, G., de Steur, L., Stewart, K. D., and Woodgate, R.: Arctic freshwater export: Status, mechanisms, and prospects, Global Planet. Change, 125, 13-35, doi: 10.1016/j.gloplacha.2014.11.013, 2015.

Hibler, W. D.: A Dynamic Thermodynamic Sea Ice Model, J. Phys. Oceanogr., 9, 815-846, doi: 10.1175/1520-0485(1979)009<0815:ADTSIM>2.0.CO;2, 1979.

Hunke, E. C. and Dukowicz, J. K.: An Elastic–Viscous–Plastic Model for Sea Ice Dynamics, J. Phys. Oceanogr., 27, 1849-1867, doi: 10.1175/1520-0485(1997)027<1849:AEVPMF>2.0.CO;2, 1997.

Karcher, M., Kauker, F., Gerdes, R., Hunke, E., and Zhang, J.: On the dynamics of Atlantic Water circulation in the Arctic Ocean, J. Geophys. Res-Oceans., 112, C04S02, doi:10.1029/2006JC003630, 2007.

Kauker, F., Gerdes, R., Karcher, M., and Köberle, C.: Impact of North Atlantic Current changes on the Nordic Seas and the Arctic Ocean, J. Geophys. Res-Oceans., 110, C12002, doi:10.1029/2004JC002624, 2005.

Kauker, F., Gerdes, R., Karcher, M., Köberle, C., and Lieser, J. L.: Variability of Arctic and North Atlantic sea ice: A combined analysis of model results and observations from 1978 to 2001, J. Geophys. Res-Oceans., 108, 3182, doi:10.1029/2002JC001573, 2003.

Köberle, C., and Gerdes, R.: Mechanisms Determining the Variability of Arctic Sea Ice Conditions and Export. J. Climate, 16, 2843–2858, doi: 10.1175/1520-0442(2003)016<2843:MDTVOA>2.0.CO;2. 2003.

Kwok, R.: Baffin Bay ice drift and export: 2002–2007, Geophys. Res. Lett., 34, L19501, doi:10.1029/2007GL031204, 2007.

Kwok, R.: Variability of Nares Strait ice flux, Geophys. Res. Lett., 32, L24502, doi:10.1029/2005GL024768, 2005.

Laidre, K. L. and Heide-Jørgensen, M. P.: Arctic sea ice trends and narwhal vulnerability, Biol. Conserv., 121, 509-517, doi: 10.1016/j.biocon.2004.06.003, 2004.

Landy, J., C., Petty, A. A., Tsamados, M., and Stroeve, J. C.: Sea ice roughness overlooked as a key source of uncertainty in CryoSat-2 ice freeboard retrievals. J. Geophys. Res-Oceans., 125, e2019JC015820. doi: 10.1029/2019JC015820, 2020.

Landy, J., C., Tsamados, M., and Scharien, R., K.: A Facet-Based Numerical Model for Simulating SAR Altimeter Echoes from Heterogeneous Sea Ice Surfaces, IEEE T. Geosci. Remote, 57, 4164-4180, doi: 10.1109/TGRS.2018.2889763, 2019.

Landy, J. C., Ehn, J. K., Babb, D. G., Thériault, N., and Barber, D. G.: Sea ice thickness in the Eastern Canadian Arctic: Hudson Bay Complex & Baffin Bay, Remote Sens. Environ., 200, 281-294, doi: 10.1016/j.rse.2017.08.019, 2017.

Landy, J., Ehn, J., Shields, M., and Barber, D.: Surface and melt pond evolution on landfast first-year sea ice in the Canadian Arctic Archipelago, J. Geophys. Res-Oceans., 119, 3054-3075, doi: 10.1002/2013JC009617, 2014.

带格式的: 缩进: 左侧: 0 厘米, 悬挂缩进: 1.98 字符, 行距: 1.5 倍行距

带格式的: 缩进: 左侧: 0 厘米, 悬挂缩进: 1.98 字符

删除了: doi:

Meier, W. N., Stroeve, J., and Gearheard, S.: Bridging perspectives from remote Sensing and Inuit communities on changing Sea-ice cover in the Baffin Bay region, Ann. Glaciol., 44, 433-438, doi: 10.3189/172756406781811790, 2006.

Min, C., Mu, L., Yang, Q., Ricker, R., Shi, Q., Han, B., Wu, R., and Liu, J.: Sea ice export through the Fram Strait derived from a combined model and satellite data set, The Cryosphere, 13, 3209-3224, doi: 10.5194/tc-13-3209-2019, 2019.

Mu, L., Losch, M., Yang, Q., Ricker, R., Losa, S., and Nerger, L.: The Arctic sea ice drift simulation from October 2010 to December 2016, doi: 10.1594/PANGAEA.906973, 2019.

Mu, L., Losch, M., Yang, Q., Ricker, R., Losa, S. N., and Nerger, L.: Arctic-Wide Sea Ice Thickness Estimates from Combining Satellite Remote Sensing Data and a Dynamic Ice-Ocean Model with Data Assimilation During the CryoSat-2 Period, J. Geophys. Res-Oceans., 123, 7763-7780, doi: 10.1029/2018JC014316, 2018a.

Mu, L., Losch, M., Yang, Q., Ricker, R., Losa, S., and Nerger, L.: The Arctic combined model and satellite sea ice thickness (CMST) dataset, doi: 10.1594/PANGAEA.891475, 2018b.

Pizzolato, L., Howell, S. E. L., Dawson, J., Laliberté, F., and Copland, L.: The influence of declining sea ice on shipping activity in the Canadian Arctic, Geophys. Res. Lett., 43, 12,146–12,154, doi:10.1002/2016GL071489, 2016.

Rennermalm, A. K., Smith, L. C., Stroeve, J. C., and Chu, V. W.: Does sea ice influence Greenland ice sheet surface-melt?, Environmental Research Letters, 4, 024011, doi: 10.1088/1748-9326/4/2/024011, 2009.

Ricker, R., Girard-Ardhuin, F., Krumpen, T., and Lique, C.: Satellite-derived sea ice export and its impact on Arctic ice mass balance, The Cryosphere, 12, 3017-3032, doi: 10.5194/tc-12-3017-2018, 2018.

Ricker, R., Hendricks, S., Helm, V., Skourup, H., and Davidson, M.: Sensitivity of CryoSat-2 Arctic sea-ice freeboard and thickness on radar-waveform interpretation, The Cryosphere, 8, 1607-1622, doi:10.5194/tc-8-1607-2014, 2014.

Ricker, R., Hendricks, S., Kaleschke, L., Tian-Kunze, X., King, J., and Haas, C.: A weekly Arctic sea-ice thickness data record from merged CryoSat-2 and SMOS satellite data, The Cryosphere, 11, 1607-1623, doi: 10.5194/tc-11-1607-2017, 2017.

Saha, S., Moorthi, S., Wu, X., Wang, J., Nadiga, S., Tripp, P., Behringer, D., Hou, Y.-T., Chuang, H.-y., Iredell, M., Ek, M., Meng, J., Yang, R., Mendez, M. P., van den Dool, H., Zhang, Q., Wang, W., Chen, M., and Becker, E.: The NCEP Climate Forecast System Version 2, J. Climate, 27, 2185–2208, doi: 10.1175/JCLI-D-12-00823.1, 2014.

Schweiger, A., Lindsay, R., Zhang, J., Steele, M., Stern, H., and Kwok, R.: Uncertainty in modeled Arctic sea ice volume, J. Geophys. Res-Oceans., 116, C00D06, doi:10.1029/2011JC007084, 2011.

Semtner, A. J.: A Model for the Thermodynamic Growth of Sea Ice in Numerical Investigations of Climate, J. Phys. Oceanogr., 6, 379-389, doi: 10.1175/1520-0485(1976)006<0379:AMFTTG>2.0.CO;2, 1976.

Serreze, M. C., Barrett, A. P., Slater, A. G., Woodgate, R. A., Aagaard, K., Lammers, R. B., Steele, M., Moritz, R., Meredith, M., and Lee, C. M.: The large-scale freshwater cycle of the Arctic, J. Geophys. Res-Oceans., 111, C11010, doi: 10.1029/2005JC003424, 2006.

Spencer, N. C., Grant, G. H., L., M. M., and Hans-Ulrich, P.: Annual Movement Patterns of Endangered Ivory Gulls: The Importance of Sea Ice, Plos One, 9, e115231, doi: 10.1371/journal.pone.0115231, 2014.

删除了: doi:

Spreen, G., de Steur, L., Divine, D., Gerland, S., Hansen, E., & Kwok, R.: Arctic sea ice volume export through Fram Strait from 1992 to 2014, J. Geophys. Res-Oceans., 125, e2019JC016039, doi: 10.1029/2019JC016039, 2020.

Stroeve, J. C., Mioduszewski, J. R., Rennermalm, A., Boisvert, L. N., Tedesco, M., and Robinson, D.: Investigating the local-scale influence of sea ice on Greenland surface melt, The Cryosphere, 11, 2363-2381, doi: 10.5194/tc-11-2363-2017, 2017.

Sumata, H., Kauker, F., Karcher, M., and Gerdes, R.: Covariance of Optimal Parameters of an Arctic Sea Ice–Ocean Model, Mon. Wea. Rev., 147, 2579-2602, doi: 10.1175/MWR-D-18-0375.1, 2019a.

Sumata, H., Kauker, F., Karcher, M., and Gerdes, R.: Simultaneous Parameter Optimization of an Arctic Sea Ice–Ocean Model by a Genetic Algorithm, Mon. Wea. Rev., 147, 1899-1926, doi: 10.1175/MWR-D-18-0360.1, 2019b.

Tang, C. C. L., Ross, C. K., Yao, T., Petrie, B., DeTracey, B. M., and Dunlap, E.: The circulation, water masses and sea-ice of Baffin Bay, Prog. Oceanogr., 63, 183-228, doi: 10.1016/j.pocean.2004.09.005, 2004.

Tian-Kunze, X., Kaleschke, L., Maaß, N., Mäkynen, M., Serra, N., Drusch, M., and Krumpen, T.: SMOS-derived thin sea ice thickness: algorithm baseline, product specifications and initial verification, The Cryosphere, 8, 997-1018, doi: 10.5194/tc-8-997-2014, 2014.

Tietsche, S., Alonso-Balmaseda, M., Rosnay, P., Zuo, H., Tian-Kunze, X., and Kaleschke, L.: Thin Arctic sea ice in L-band observations and an ocean reanalysis, The Cryosphere, 12, 2051-2072, doi: 10.5194/tc-12-2051-2018, 2018.

Tschudi, M.A., W.N. Meier, and J.S. Stewart, 2020. An enhancement to sea ice motion and age products at the National Snow and Ice Data Center (NSIDC). The Cryosphere, 14,1519-1536, doi: 10.5194/tc-14-1519-2020.

Tschudi, M., Meier, W. N., Stewart, J. S., Fowler, C., and Maslanik, J.: Polar Pathfinder Daily 25km EASE-Grid Sea Ice Motion Vectors, Version 4, Boulder, Colorado USA, NASA National Snow and Ice Data Center Distributed Active Archive Center, doi: 10.5067/INAWUWO7QH7B, 2019.

Wang, X., Key, J., Kwok, R., and Zhang, J.: Comparison of Arctic Sea Ice Thickness from Satellites, Aircraft, and PIOMAS Data, Remote Sens., 8, 713, doi: 10.3390/rs8090713, 2016.

Warren, S. G., Rigor, I. G., Untersteiner, N., Radionov, V. F., Bryazgin, N. N., Aleksandrov, Y. I., and Colony, R.: Snow Depth on Arctic Sea Ice, J. Climate, 12, 1814-1829, doi: 10.1175/1520-0442(1999)012<1814:SDOASI>2.0.CO;2, 1999.

Xie, J., Counillon, F., and Bertino, L.: Impact of assimilating a merged sea-ice thickness from CryoSat-2 and SMOS in the Arctic reanalysis, The Cryosphere, 12, 3671-3691, doi: 10.5194/tc-12-3671-2018, 2018.

Yang, Q., Losa, S. N., Losch, M., Jung, T., and Nerger, L.: The role of atmospheric uncertainty in Arctic summer sea ice data assimilation and prediction, Q.J.R. Meteorol. Soc., 141, 2314-2323, doi: 10.1002/qj.2523, 2015.

Zhang, J. and Rothrock, D. A.: Modeling Global Sea Ice with a Thickness and Enthalpy Distribution Model in Generalized Curvilinear Coordinates, Mon. Wea. Rev., 131, 845-861, doi: 10.1175/1520-0493(2003)131<0845:MGSIWA>2.0.CO;2, 2003.

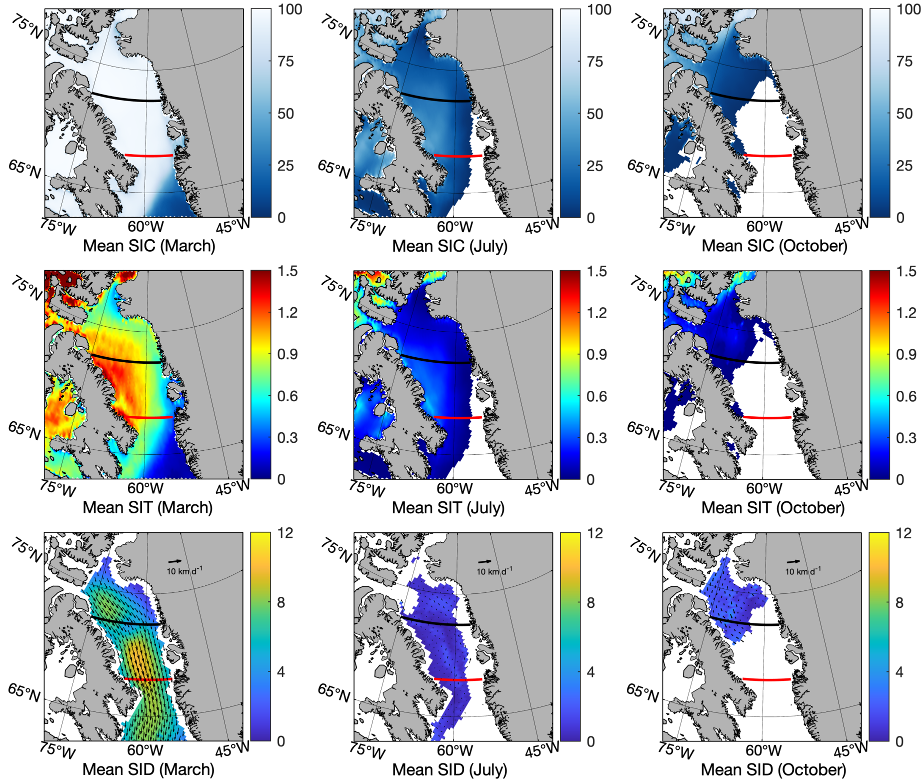
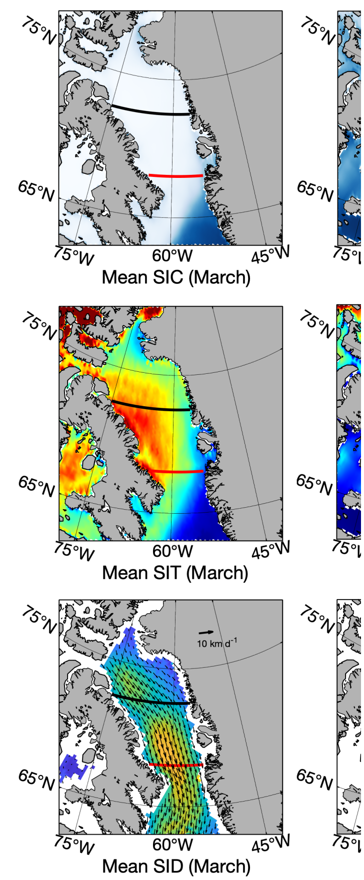


Figure 1. The ensemble mean sea ice concentration (top row: SIC, unit: %) and thickness (middle row: SIT, unit: m) in March, July, and October averaged from CMST, NAOSIM, PIOMAS and Sat-merged SIT over the period 2011-2016. Sea ice drift (bottom row: SID, unit: km d^{-1}) is calculated by averaging data from NSIDC. Note that the Sat-merged SIT in the ensemble are only valid in March and October.



删除了:

带格式的: 题注, 行距: 1.5 倍行距

删除了: xx…011-xx…016. Sea ice drift (bottom row: SID, unit: km d^{-1}) is calculated by averaging data from NSIDC and OSISAF… ... [115]

删除了: from CMST, NAOSIM,

删除了: and

删除了: PIOMAS and

删除了: and OSISAF drift

删除了: (only for…March and October) for the long-term March, July, and October mean ... [116]

The black line shows the SIV inflow gate, and the red line denotes the SIV outflow gate in the Baffin Bay.

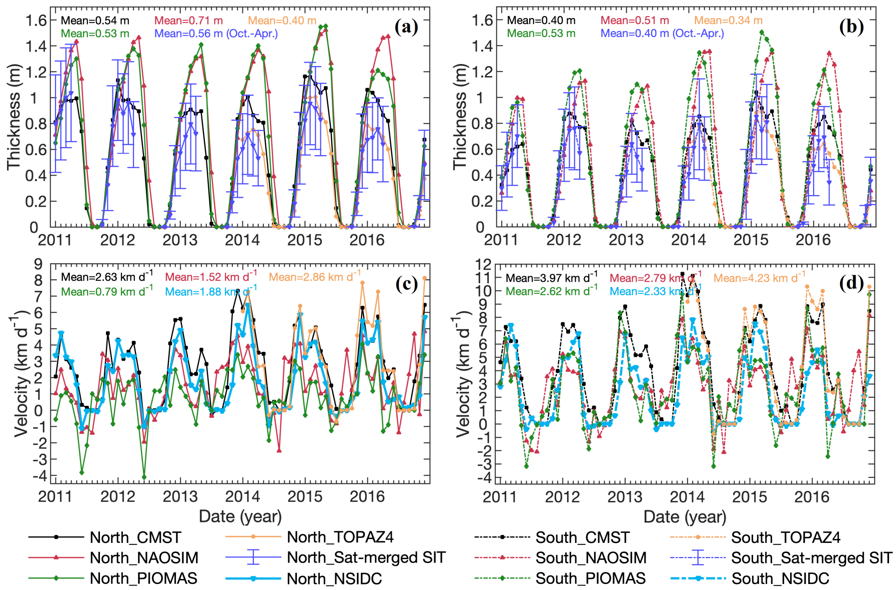
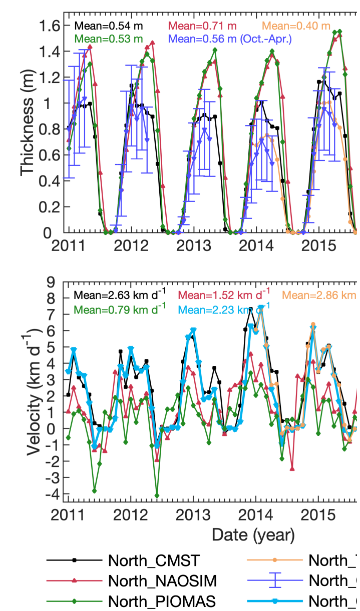


Figure 2. The monthly mean variations of sea ice thickness and southward velocity over the northern inflow gate and southern outflow gate (SIT: a and b, SID: c and d). The full lines in the left panel and dashed lines in the right panel represent sea ice variables over the north gate and south gate, respectively. The different colours denote different input sea ice data. Note that the Sat-merged SIT with corresponding uncertainty is from a locally merged sea ice data in the Baffin Bay.

删除了: The drift (bottom row: SID, unit: km d-1) is from NSIDC and OSISAF (only for March and October).

删除了:



删除了:

删除了: inflow gate and outflow gate

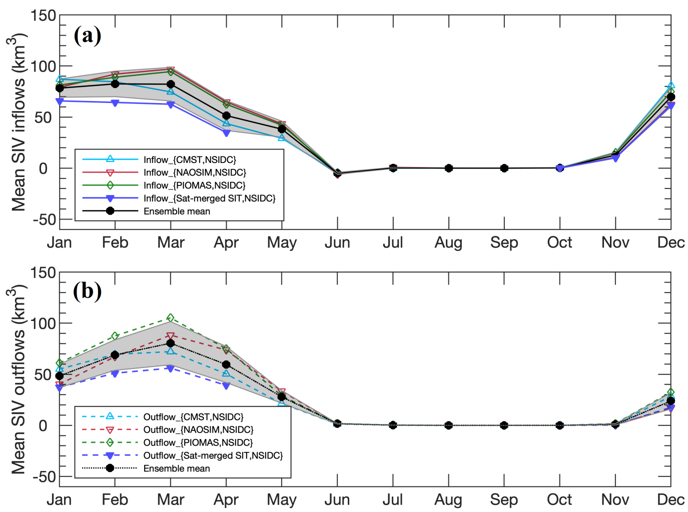
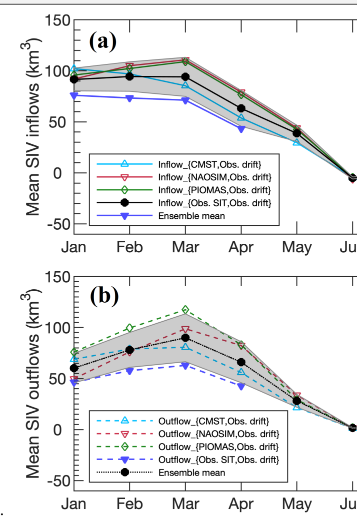


Figure 3. Averaged sea ice volume (SIV) (a) inflows through the north gate and (b) outflows through the south gate between 2011 and 2016. The cyan lines are the fluxes derived from CMST SIT and NSIDC SID, the red lines indicate estimates from NAOSIM SIT and NSIDC SID, the green lines denote the fluxes from PIOMAS SIT and NSIDC SID, the blue line is for the fluxes from Sat-merged SIT and NSIDC SID and the black lines represent the ensemble mean fluxes from the four inflows and outflows, respectively. Shaded areas indicate the standard deviation derived from the four different inflows and outflows, respectively.



删除了:

删除了: NSIDC SID

删除了: ions

删除了: NSIDC SID

设置了格式: 字体颜色: 文字 1

删除了: NSIDC SID

删除了: three

删除了: three

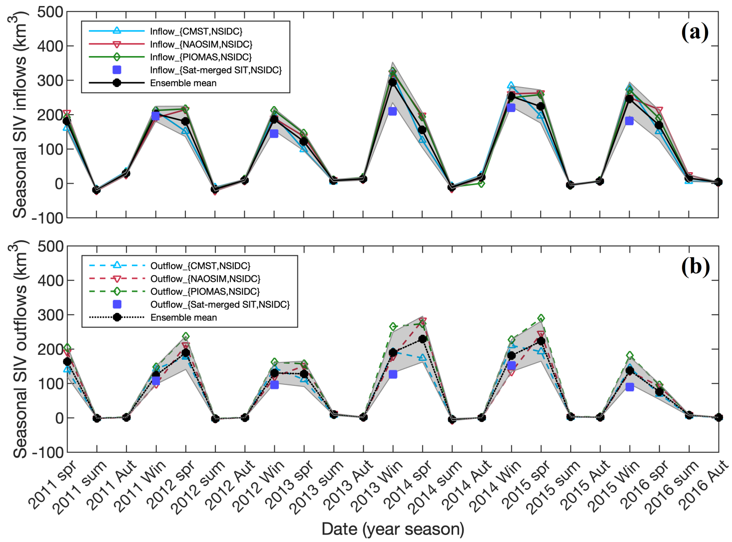
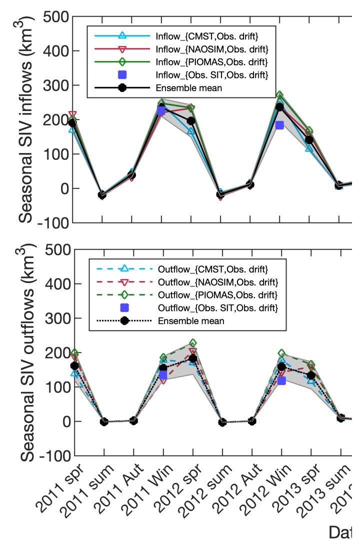


Figure 4. As Fig. 3 but for long-term seasonal evolution of sea ice inflows and outflows. Note that these blue squares represent the SIV fluxes from Sat-merged SIT and NSIDC SID.



删除了:

删除了: As Fig. 3 but for the long-term seasonal evolution of sea ice inflows and outflows.

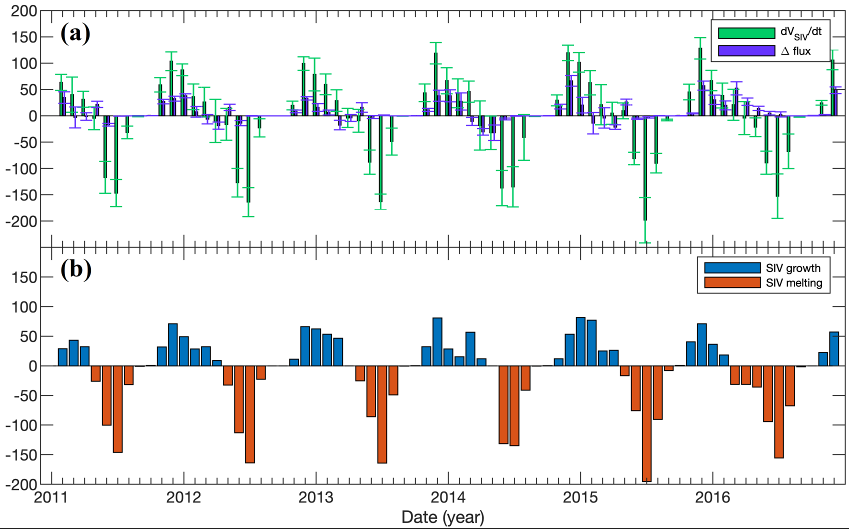
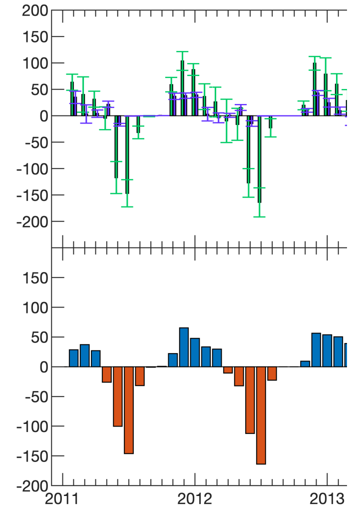


Figure 5. The ensemble mean sea ice volume changes from net ice flux and thermodynamics growth. (a) The ensemble mean SIV variability (dV_{SIV}/dt, green bar) in the defined Baffin Bay area and the net SIV flux (Δflux, purple bar) together with the ensemble spread (error bar). (b) The SIV variability derived from ice freezing (blue bar) and melting (orange bar) in the defined area.



删除了:

删除了:

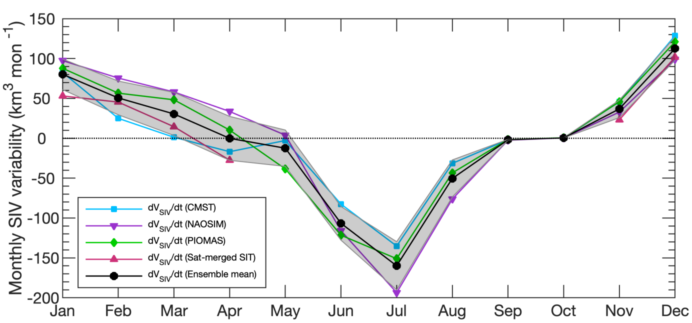


Figure 6. The sea ice volume changes from CMST (dV_{SIV}/dt (CMST), cyan line), NAOSIM (dV_{SIV}/dt (NAOSIM), purple line), PIOMAS (dV_{SIV}/dt (PIOMAS), green line), satellite observation (dV_{SIV}/dt (Sat-merged SIT), violet red line) and the ensemble mean (dV_{SIV}/dt (Ensemble mean), black line) in the Baffin Bay area. The shading indicates the ensemble spread (one standard deviation).

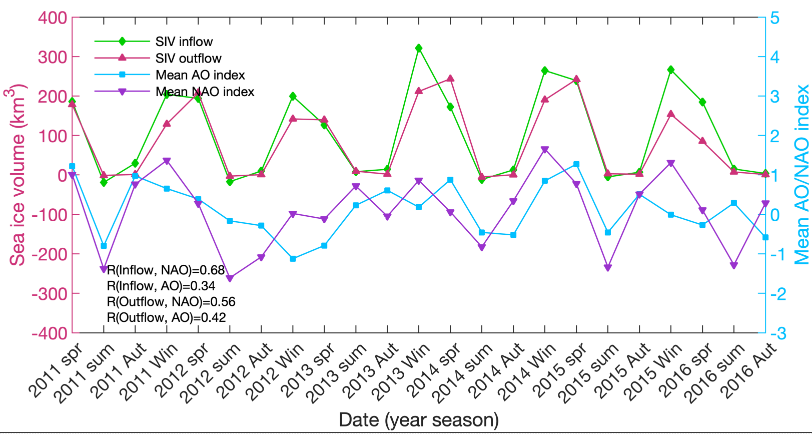
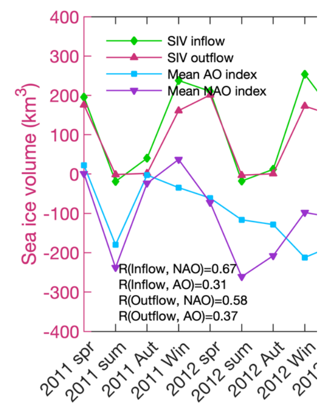


Figure 7. Time series of seasonal mean SIV inflow (green line), outflow (violet red line) in the Baffin Bay. The NAO (purple line) and AO (cyan line) indexes are averaged in the same period. R represents the correlation coefficient between NAO/AO and inflow and outflow.

删除了: **Figure 6.** The sea ice volume variabilities from CMST (dV_{SIV}/dt (CMST), cyan line), NAOSIM (dV_{SIV}/dt (NAOSIM), purple line), PIOMAS (dV_{SIV}/dt (PIOMAS), green line) and the ensemble mean (dV_{SIV}/dt (Ensemble mean), black line) in the Baffin Bay area. The shading indicates the ensemble spread (one standard deviation).



删除了:

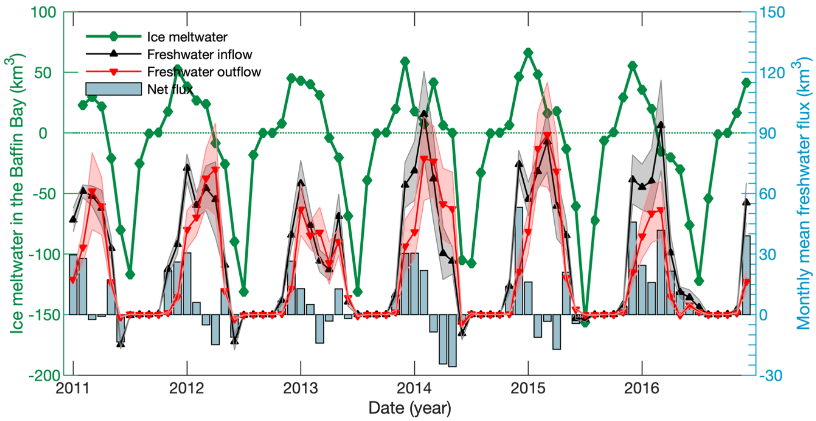
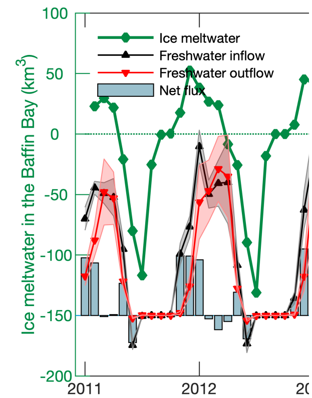


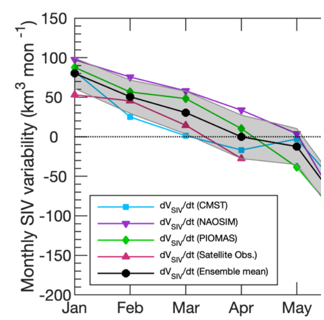
Figure 8. Freshwater from sea ice inflow (black line) through the north gate and outflow (red line) through the south gate (Davis Strait), and sea ice growth/melting (green line) in the Baffin Bay. The net flux of freshwater derived from net SIV flux (i.e., sea ice inflow minus outflow) are presented in skyblue bar.

Table 1. Monthly mean freshwater fluxes (km^3 month^{-1}) imported into the Labrador Sea that derive from the sea ice volume outflow

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CMST_NSIDC	44	56	58	40	17	1	0	0	0	0	1	23
NAOSIM_NSIDC	32	54	71	59	27	1	0	0	0	0	1	13
PIOMAS_NSIDC	49	70	84	60	23	1	0	0	0	0	1	26
Sat-merged SIT_NSIDC	30	41	45	31	-	-	-	-	-	0	0	14
Ensemble mean	39	55	65	48	22	1	0	0	0	0	1	19



删除了:



删除了:

删除了: fresh water

删除了: d

删除了: inflow

删除了: s

删除了:
Jan ... [117]

设置了格式: 字体: 10 磅

设置了格式: 字体: 10 磅

设置了格式: 字体: 10 磅

设置了格式: 字体: 10 磅

设置了格式: 字体: 10 磅

设置了格式: 字体: 10 磅