Dear reviewer,

Thank you for your comments. Based on the evaluations, we have made a major revision of our manuscript as below:

1, We added quantitative analysis on the impact of the cloud in section 5.3.

2, We analyzed the retrieval accuracy of different sea ice velocity in section 5.5.

3, We checked the buoy validation issue and made the necessary modifications in section 4.2.

Please see below our response (blue text) to your comments (black text) point-by-point. We have carefully reviewed and addressed all of comments which we hope meet with approval.

Thank you for your time and help,

Best regards,

Dunwang Lu and co-authors

Responses to Reviewer's Comments:

Reviewer #1:

General comments

- **GC: "The biggest problem with optical remote sensing is the impact of clouds. Although the paper has discussed the impact of clouds on sea ice motion products, the extent of the impact and its impact on the effective data are not very clear. Further clarification is needed. In addition, it is also necessary to consider whether the topographic features of summer sea ice surfaces, such as snow hummocks and ice ridges, have an impact on the inversion results. The impact of sea ice motion speed itself on the errors of data product needs to be further quantified, and the spatial and seasonal differences in retrieval errors also need to be quantitatively explained. At present, the paper mainly uses examples to illustrate the above issues, rather than providing statistical results, which is not conducive to objective evaluation of the data product."**

Response: Thank you for your valuable comments. According to your comments, we modified our manuscript in the following four aspects:

(1) The impact of clouds on SID products

The cloud is the main drawbacks for the SID retrieval with optical imagery and it effect the coverage of the SID product. At present, the SID based on AVHRR is the only SID product retrieved from optical imagery (e.g., Wang et al., 2022). In our study, the sea ice under thin cloud can be detected with appropriately preprocessing, which increase the coverage of our product. We used whiteness index (Gómez-Chova et al., 2008) and MED (Multiscale Edge-preserving Decompositions) (Farbman et al., 2008) to detect the cloud pixel (Kang et al., 2018) and to analyze the effect of cloud quantitatively. The following text and figure have been added into the section 5.3 of our manuscript as "The potential of retrieving sea ice drift from image with cloud".

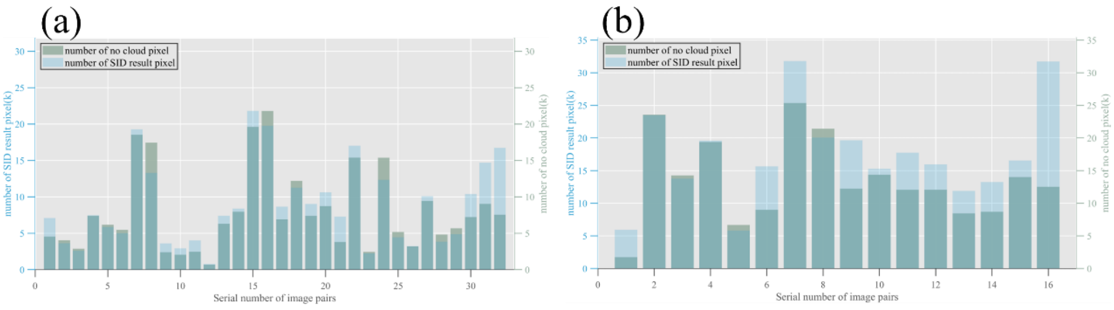

Figure 17: The number of no-cloud pixels (green) and retrieved SID pixels (blue) (a: day-level result, b: hours-level result).

To quantify the potential of retrieving SID from image with cloud, we use the whiteness index (Gómez-Chova et al., 2008) and Multiscale Edge-preserving Decompositions (MED) (Farbman et al., 2008) to detect the cloud pixels (Kang et al., 2018). Fig .17(a) and (b) show the number of no-cloud pixels and the number of retrieved SID pixels. For the day-level results, in addition to the influence of cloud pixels, dramatic shape changes of sea ice also hinder the retrieval of SID. As shown in Fig. 17(a), only a few (1^{st}, 15^{th}, 21^{st}, 30^{th}, 31^{st} and 32^{nd}) of the retrieved SID pixels are beyond the no-cloud pixels. For the 32nd image pair, the number of SID pixels is 120% greater than the number of no-cloud pixels, possibly because the cloud in the images is quite thin. For the hours-level results, images with short time interval provide a stable scene for retrieving. Thus, many of the retrieved SID pixels (1^{st}, 6^{th}, 7^{th}, 9^{th} and 11^{th}-16^{th}) are greater than the no-cloud pixels as shown in Fig. 17(b). For the 16th image pair, the number of retrieved SID pixels is 150% greater than the number of no-cloud pixels, this is because the cloud is slight and the distributions of cloud in two images are similar. The average of SID pixels beyond the no-cloud pixels is 10.109% and 28.920% for the day-level result and the hours-level result, respectively. In conclusion, our approach has the potential to retrieve SID effectively with images containing cloud pixels. The result shows that with less strict restriction and appropriate preprocessing, images with cloud could be used to obtain credible and dense SID.

(2) The impact of sea ice surface feature on SID products

The topographic features of sea ice are often quantified by the surface roughness and form drag (Arya, 1973, 1975) and those features do have impact on ice drift speed (Zu et al., 2021) In this study, the optical imagery of CZI with 300m spatial resolution was used for SID retrieval and this images have the better identification ability for the ice surface feature than those observation with km spatial solution. Some surface topographic features such as snow hummocks and ice ridges can not be identified with optical images. These features can be observed with SAR and laser altimeter and they can associated with the momentum exchange between sea ice and the lower atmosphere forced by wind (Zhang et al., 2024). The impact of topographic features on SID product will be the future improvements to our product. We have added some description to discuss this matter in the last paragraph of section 5.5.

(3) Quantified error of the sea ice motion speed

The impact of sea ice velocity on the accuracy of retrieval SID is imperative, so we made a new experiment and the below text has been added in the manuscript as section 5.5.
5.5 Factors affecting the accuracy of velocity retrieval.

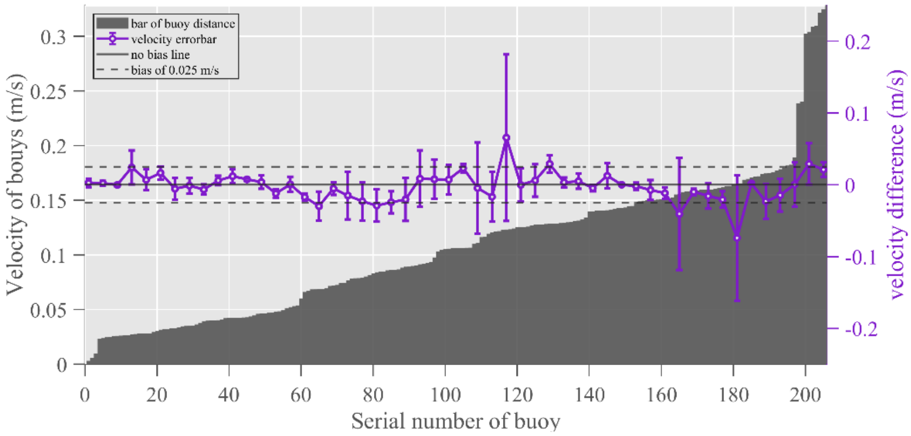

Figure 19: Relationship between the velocity difference and the velocity of the buoys.

The study area spans the Arctic basin to the Fram Strait, where the velocity of the SID generally presents complicated variations. The maximum magnitude of buoy-derived ice velocity can reach to 0.64 m/s in FS (Lei et al., 2016). Sea ice in the north of the FS or close to the land has a relatively low velocity. It is imperative to make further research on the accuracy of retrieving SID with different velocity.
In our study, the data were from March to May 2021, and we generated a total of 206 matched points and merged every 4 points to calculate the standard deviation of the velocity difference. We further analyzed the relation between the accuracy of retrieved velocity and the buoy velocity. As shown in Fig 19, the bar shows that the velocity of buoys that we used in validation ranged from 0 m/s to 0.32 m/s, and the line of bias and standard deviation shows the accuracy of the retrieved velocity which is associated with the velocity of the buoys. As the velocity of the buoys increases to 0.1 m/s, both the bias and standard deviation also increase. Although the bias of retrieved velocity occurs within in an ideal range as the velocity of the buoys increases, the standard deviation of the velocity difference becomes erratic. In general, sea ice motion with great velocity appears unstable in the images. Our algorithm still need improvement in retrieving SID with high velocity.

(4) **The spatial and seasonal distribution of retrieval errors**
The seasonal differences in retrieval errors are important. The images used in this study were collected from March to May 2021, thus we do not have enough data to analyze the seasonal change in the retrieval errors. We are considering processing HY1-C data to improve our dataset in the future experiment.
For the spatial differences in retrieval error, we generated 206 matched points and merged every 4 points to calculate the standard deviation of velocity difference. We plotted the relationship between the velocity difference and the latitude of validation buoys in the following figure, the gray bar in the X-axis refers to the latitude of the buoys. We didn't

observe the significant correlation between spatial differences and retrieval errors. It's challenging for us to explain the difference of spatial retrieval errors on the limited amount of data. Improving our dataset and including more buoys are required in future to explore the retrieval error in different region.

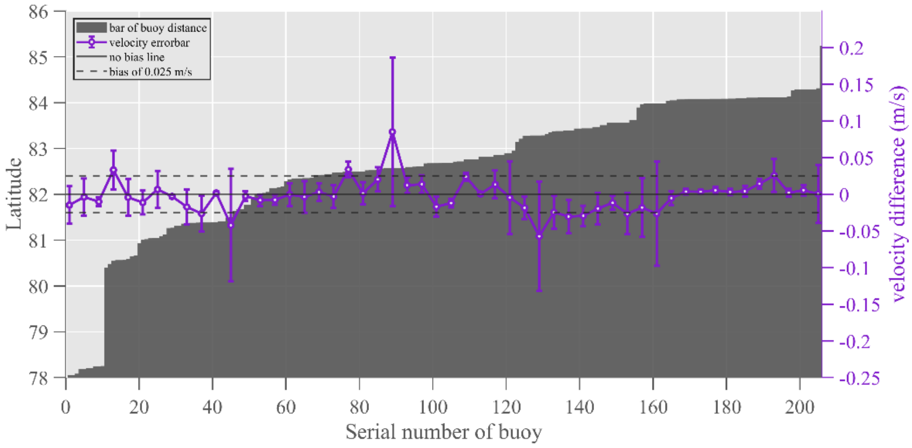

Figure: Relationship between the velocity difference and the latitude of validation pair.

Specific comments:

Line 34 "leading to accelerated sea ice break-up" -- ice break-up generally describes the situation of synoptic scale processes.

Response: Thank you for the valuable comment. We rewrite the sentence as "Arctic quick warming accelerates the melting of polar sea ice, leads to thinner sea ice and accelerates sea ice transport (Krumpen et al., 2016; Maslanik et al., 2011)."

Line 40 "the TPD transports large quantities of multiyear ice outward from the central Arctic toward the FS"-- not just the Fram Strait, but also the Barents Sea and Baffin Bay.

Response: Thank you for the valuable comment. We rewrite the sentence as "TPD transports large quantities of multiyear ice outward from the central Arctic toward the FS, Barents Sea and Baffin Bay (Colony and Thorndike, 1984; Martin and Augstein, 2000)."

Line 46 "which gradually melts during outward transport"--If the sea ice outflow occurs during winter, sea ice growth may also occur.

Response: Thank you for the valuable comment. The outflow is considered as the sea ice move from the Arctic basin to the low latitude area. We rewrite the sentence as "Sea ice, a mixture of ice and brine (Schwerdtfecer, 1963), which gradually disintegrates during outward transport in the FS." in line 46.

Line 50 "between the polar regions and the outside world"--what is the meaning of

"outside of world"

Response: Thank you for the valuable comment. We rewrite the sentence as "Therefore, observing SID in the FS is crucial to analyse the sea ice variation in the Arctic and the sea ice transport from the polar to sub-polar regions."

Line 59 "low temporal resolution SID product may fail to provide accurate sea ice drift patterns"-- The main limitation of low-temporal-resolution sea ice motion products is that they cannot depict the subdaily-scale signals of the sea ice kinematics.

Response: Thank you for the valuable comment. We rewrite the sentence as "low temporal resolution SID product may fail to depict the subdaily-scale variation of the sea ice motion."

Line 81 "However, it has been observed that the accuracy of the SID product with AVHRR is not good in s regions like East Greenland"-- What are the reasons for poor observation results?

Response: Thank you for the valuable comment. We found the conclusion that the accuracy of SID retrieved from AVHRR in east Greenland is poor in Wang's paper (Wang et al., 2022). The reason is not discussed in the paper. We think the low accuracy for the product in east Greenland is due to the disintegrated small sea ice in the FS and low spatial resolution of used images. We rewrite the sentence as "However, it has been found that the accuracy of the SID product retrieved from AVHRR presents low accuracy in East Greenland".

Line 132 "the product includes the North Pole and South Pole"--1) change to the product is available from both Arctic Ocean and South Ocean; 2) The language of the entire text must be more strictly controlled.

Response: Thank you for the valuable comment. We rewrite the sentence as "and the product is available from both Arctic Ocean and South Ocean (Pedersen et al., 2015).". We checked the language of the entire manuscript and marked our revisions in the manuscript.

Figure 2: "The drifting trajectories of 69 IABP buoys from March to May 2021": How independent are these data, that is, they are not deployed in a very close area, especially the buoys deployed during the MOSAiC; In addition, whether to conduct quality control on the data and eliminate the data with noise and buoy data that are already at sea (not over the ice).

Response: Thank you for the valuable comment. We had deployed quality control to the buoy data. We checked the location of the buoys data to make sure the buoy is placed on the ice and the corresponding description in Section 2.3 has been modified. There are some buoys are deployed in the vicinity of same SID grid. Thus, the different buoys located in the same SID grid were averaged and used to validate SID. We think that buoys in the same grid are all significative and contributing for validating the SID.

Line 156 "we design a quality control session to remove the low quality data from the results"-- How much data will be lost during the study period due to the impact of clouds?

Response: Thank you for the valuable comment. Quality control is a vital step for the quality of SID. In our study, we employed cross-correlation parameter (R), peak second ratio (PSR) and peak mean ratio (PMR) to limit quality level of the result. These parameters, especially the cross-correlation parameter, had been widely used in producing SID and also been validated as effective parameters for quality control. About the amount of the filtered data with quality control parameters, we added an explanation in section 5.3.

The error in the direction of sea ice movement: We know that the sea ice movement in the Fram Strait is relatively stable, so it is possible that the angle error may be small. Can you further evaluate the angle error of sea ice motion under different meandering coefficients?

Response: Thank you for the valuable comment. A greater meander coefficient signifies a more erratic trajectory, whereas a value of M = 1 indicates that the buoy travelled in a straight line(Womack et al., 2022). The meandering coefficient is a primary quantitative measure for the kinematics of sea-ice drift (Vihma et al., 1996). The following figure shows the retrieval angle error and the meandering coefficients of buoys. A total of 306 matched pairs are produced. The number of the matched pairs is less than 344, because that there are some buoys possess less than 3 GPS points which is inadequate for calculating the meandering coefficient. In the meander coefficients, 91.83% of them is less than 1.5. The time interval of our dataset is less than 30 hours, and the meandering coefficient of sea ice motion at short time interval is low relatively. We didn't observe the correlation between the retrieval angle error of sea ice motion and meandering coefficients. It's challenging for us to explain the relation between them because the time interval of our dataset is shorter than one day.

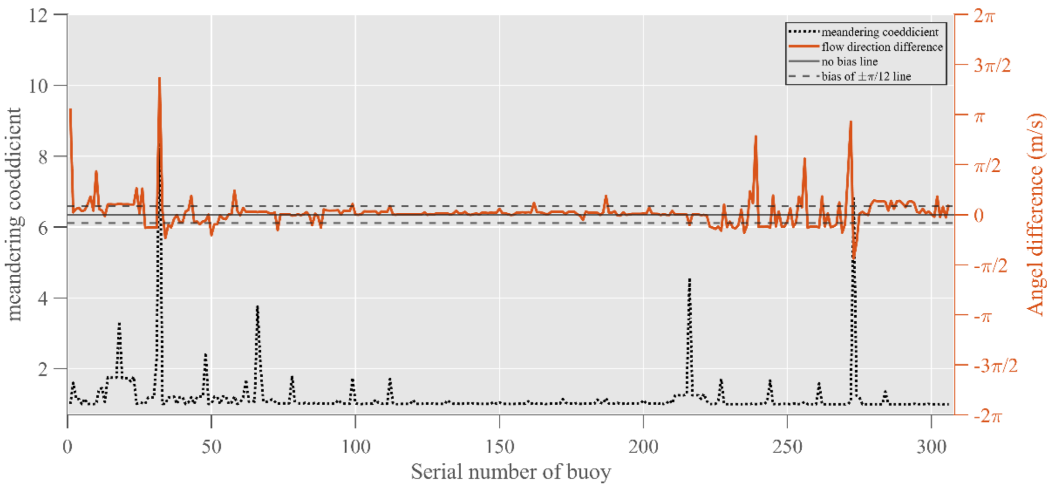

Figure: The retrieval angle error and the meandering coefficient of buoy.

Hourly data: Does the data have the ability to identify the subdaily-scale characteristics of sea ice motion and compare them with buoy data on a frequency basis?

Response: Thank you for the valuable comment. Comparing with the buoys, CZI data has lower frequency in capturing the subdaily-sacle characteristics of sea ice motion. But CZI has wide swath and can provide 3 times observations in one day over a specific area of Arctic. There are more times observation if we combine HY-1C and HY-1D, which supply a good data source for identifying the subdaily-scale characteristics of sea ice motion.

BIAS: Relative deviation is also very important.

Response: Thank you for the valuable comment. We had added the relative deviation of bias into Table 3 and 4.

Table 3: Validation of the retrieved SID (day-level) with IABP buoys.

Delta	Number of match point	BIAS (Relative deviation$_{mean}$)	MAE	STD	RMSE
Velocity (m/s)	132	-0.005(-1.330%)	0.018	0.031	0.031
Flow direction (rad)		0.002(0.149%)	0.003	0.009	0.009

Table 4: Validation of the retrieved SID (hours-level) with IABP buoys.

Delta	Number of match point	BIAS (Relative deviation$_{mean}$)	MAE	STD	RMSE
Velocity (m/s)	74	0.000(1.998%)	0.021	0.036	0.036
Flow direction (rad)		0.003(0.154%)	0.006	0.010	0.010

Figure 12: What is the confidence level of the correlation coefficient?

Response: Thank you for the valuable comment. The confidence level is an important parameter for correlation coefficient, we had added the 95% confidence level bar in the figure 12, and also added necessary descriptions and analysis for the figure in the manuscript.

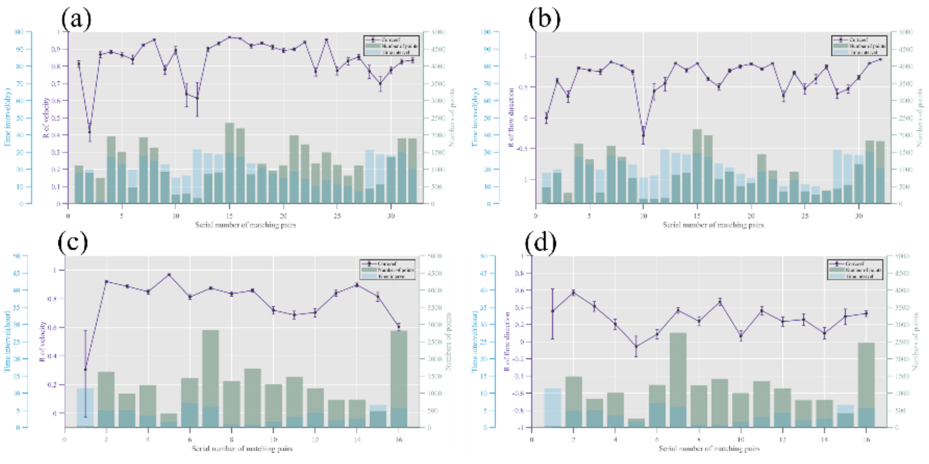

Figure 12: The correlation coefficient and 95% confidence level bar of correlation coefficient between the retrieved SID and the CMEMS SID product. (a), (b): The correlation coefficient between the retrieved SID (day-level) and the product in terms of velocity and flow direction. (c), (d): The correlation coefficient between retrieved SID (hours-level) and the product in terms of velocity and flow direction. The green histogram (right axis) shows the number of matched points between the retrieved SID and the product, and the blue histogram (the first left axis) shows the time interval between the retrieved SID and the product.

Figure 15: In the caption of the illustration, a lot of information is missing, which is only appear in the main text.

Response: Thank you for the valuable comment. We rewrite the illustration as "Figure 15: The buoy velocity (a) and flow direction (c) and the difference (velocity (b), flow direction (d)) between the retrieved SID and buoys. The lines in blue represents SID and buoy vectors with day-level time interval and the lines in yellow, gray and purple represents SID and buoy vectors with hours-level time interval on the same day. The x-axis shows the different matched SID and buoys. The y-axis in (b) and (d) show the difference between SID and buoys".

Figure 16: This is an obvious result, and this illustration is not necessary. It is necessary to add an explanation of the classification evaluation under different conditions with various meandering coefficients and sea ice motion speed. And provide clustering statistical results for different sub regions.

Response: Thank you for the valuable comment. We deleted the figure in the manuscript. The following figure shows the retrieval velocity error and the meandering coefficients of buoys. A total of 306 matched pairs are produced. In the meander coefficients, 91.83% of them is less than 1.5. We didn't observe the correlation between the retrieval velocity error of sea ice motion and meandering coefficients. We set 80°N as the segmentation line and calculated the mean value of meandering coefficients and retrieval errors. In the northern of the segmentation line, the mean of meandering coefficient and velocity error are 1.175, 0.005 m/s, and the number of points is 296. In the southern of the segmentation line, the mean of meandering coefficient and velocity error are 1.033, -0.010 m/s, and the number of points is 10. A greater meander coefficient signifies a more erratic trajectory. The mean of meander coefficient in the southern of the segmentation line should be bigger than the mean of meander coefficient in the northern of the segmentation line. We think that the reliability of our experiment about meandering coefficient is insufficient because of the limited number of matched pair.

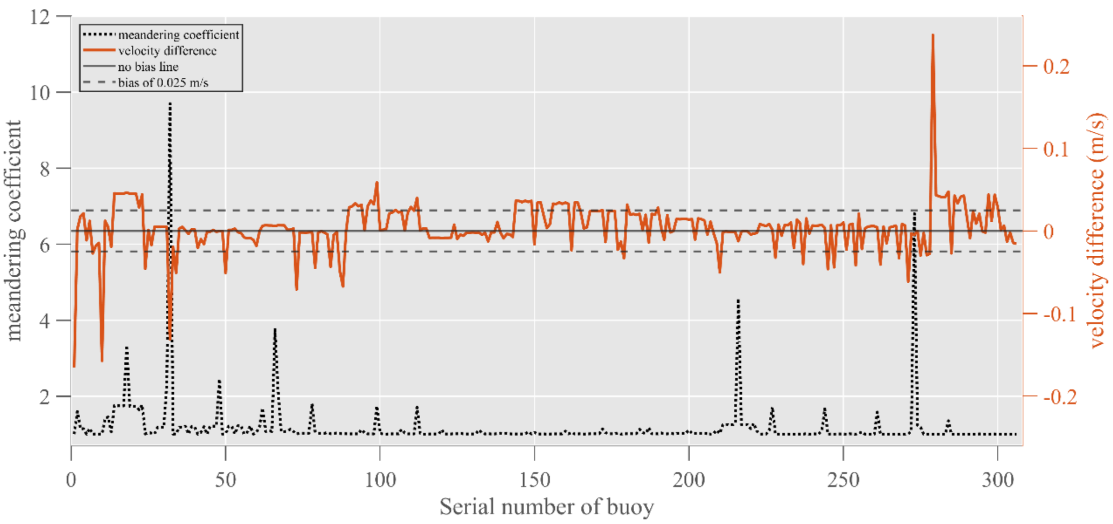

Figure: The retrieval velocity error and the meandering coefficient of buoy.

Reference:

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