Dear reviewer

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

1, We analyze the effectiveness and spatial distribution of quality control parameters in section 5.6.

2, We added the necessary description of the uncertainties of the CMEMS SID product and IABP buoys in section 2.

3, We have fixed the problems in Fig. 14 and Fig. 18.

4, We carefully checked the language of the manuscript and made revisions

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 #2:

General comments

- **GC: "The authors used the IABP buoy to validate the product, but due to lacking of on-site observation data, there are uncertainties for the quality of product. The quality control is used to ensure the quality of product and the distribution of these parameters magnitude requires discussion. The spatial resolution of sea ice drift is different with those of the IABP buoy and CMEMS SAR products. How the authors process the problems during the comparisons between them. Additionally, the authors should illustrate the uncertainties for CMEMS SAR products and IABP buoy which will bring biases for comparative results. I suggest the authors to carefully proofread the manuscript and resolve all language issues, as it would be very difficult to pin-point all such issues."**

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

(1) Uncertainty of the validation data

For the uncertainty of the CMEMS SID product, we check the user manual and find the validation of the product with ITP buoys. The number of matched pair is 29180, the correlation coefficient between the product and ITP buoys is 0.99, and RMSD of dx and dy is 362.32 m (0.0042 m/s) and 339.81 m (0.0039 m/s), the BIAS of dx and dy is 4.64 m and 17.29 m and the BIAS of velocity is negligible (~0 m/s). The time of validation is 2021 and the validation is performed with the 24-hour mean composite product. The website for the

validation report of the product is http://www.seaice.dk/Copernicus/validation. The validation from the following table proves that the product presents high accuracy.

Table: Latest validation results of the CMEMS SID product.

year	metric	coordinate	Value/[m]
2021	RMSD, mean	X	362
		Y	340
	BIAS, mean	X	5
		Y	17
2022	RMSD, mean	X	298
		Y	402
	BIAS, mean	X	-2
		Y	-6
2023	RMSD, mean	X	223
		Y	236
	BIAS, mean	X	-7
		Y	-3

As for the uncertainty of buoys, we used two kinds of buoys in validation. The GPS position of MOSAiC buoys has an accuracy of ± 2.5 m (Qiu and Li, 2022) which is sufficiently ideal for retrieved SID validation. As for IABP buoy, the buoy positions have an accuracy about 300 m(Haarpaintner, 2006), which is negligible relative to the SID resolution of 4 km.

The necessary descriptions about the uncertainties of the CMEMS SID product and IABP buoys have been added to the section 2.

(2) Comparison method with buoy data and SAR data

About the comparison with the buoy, we selected the adjacent buoys in the same SID grid (4km) firstly, then calculated the mean value of the selected buoys (Lavergne et al., 2021; Hwang, 2013; Lavergne et al., 2010).

For the comparison with the CMEMS SID product, the spatial resolution of the product is 10 km and the spatial resolution of retrieved SID is 4 km. The retrieved result was resampled from 4km into 10 km with linear interpolation. The necessary descriptions of comparison have been added to the manuscript.

(3) Quality control parameters

To evaluate the quality of SID, we analyzed the effectiveness of the quality control parameters. The following text was added to the manuscript.

To validate the effectiveness of quality control parameters, a comprehensive examination was undertaken, involving a comparative analysis between the quality control parameters and buoy validation of the SID. The red line in Fig. 21 shows the R of the validation points, and to identify the relationships between R and the other parameters, the data are sorted in ascending order by R. The bar in orange and bar in blue represent the PMR and PSR, respectively. The figure revealed a pronounced congruence, wherein the R, PMR and PSR exhibited coherent consistency. A positive correlation was discerned, indicating that the increase in R proportionally accompanies the increase in the PMR and PSR. The magnitude of R has been extensively used as a quality control parameter for SID retrieval (Qiu and

Li, 2022; Haarpaintner, 2006; Robert Ezraty et al., 2007). Given the observed synchronous trends of the PMR, PSR and R, it is evident that the PMR and PSR collectively demonstrate efficacy in quality control. In Fig. 21, the error-bar in purple shows the difference between the retrieved SID and buoys. The bias and standard deviation of the retrieved SID diminish as R, the PMR and the PSR increase, which indicates the effectiveness of these parameters for revealing the reliability of the result.

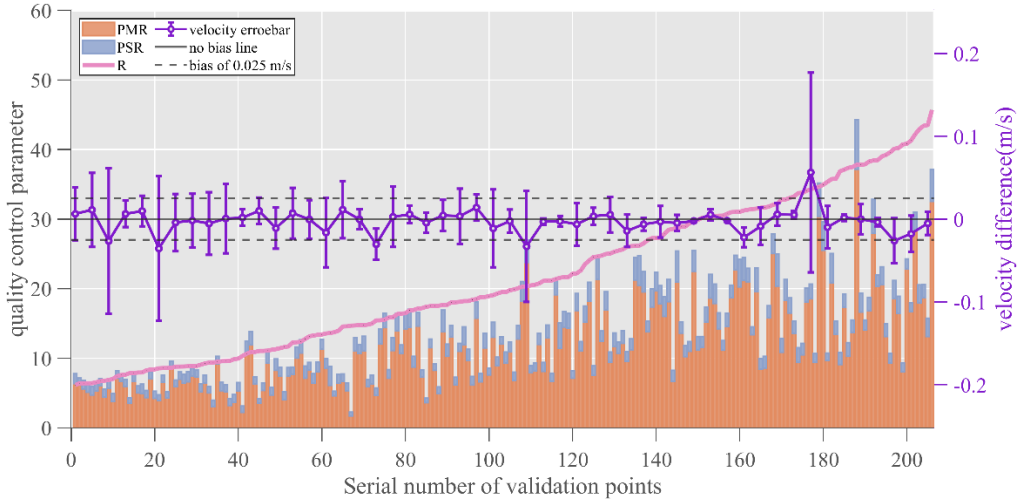

Figure 21: Relationship between the velocity difference and quality control parameters.

(4) Language issues

We have carefully reviewed the manuscript and made revisions. The revisions are marked in the manuscript.

Specific comments:

Line 16: "has been retrieving" should be "has been retrieved"

Response: Thanks for the valuable comment, we have fixed the mistake.

Line 37-38: "and it is the process of sea ice as it moves across the sea surface in response to winds, currents and other forces"- Rephrase this statement.

Response: Thank you for the valuable comments. We rewrote the sentence as 'Sea ice drift (SID) is an important geophysical parameter to describe the dynamic of sea ice and the sea ice motion under the influence of winds, currents, and various external forces'.

Line 39: the word "consist of" is not quite appropriate. Please recheck it

Response: Thank you for the valuable comment. We rewrote the sentence as 'The primary SID circulation across the Arctic encompasses both the Beaufort Gyre (BG) and the Transpolar Drift (TPD)'.

Line 40: "the TPD" should be "TPD"

Response: Thanks for the valuable comment, we have fixed the mistake.

Line 51: "With the launch of many remote sensing satellites…" this statement is too colloquial and rewrite it.

Response: Thank you for the valuable comment. We rewrote the sentence as 'The development of satellites and remote sensing sensors promote satellite data as a prevailing trend in retrieving SID'.

Line 55: "Products" should be "products"

Response: Thanks for the valuable comment, we have fixed the mistake.

Line 56: "…yield lower-resolution due to"- Please recheck this sentence.

Response: Thank you for the valuable comment. We rewrote the sentence as 'SID products derived from radiometers and scatterometers inherently possess coarse spatial resolution owing to the characteristics of the sensors.'

Line 57: "OSI SAF scatterometer and radiometer based on SID products are available for many years…" should be "OSI SAF SID products based on scatterometer and radiometer are …"-Please recheck it.

Response: Thank you for the valuable comment. We rewrote the sentence as 'OSI SAF provides SID products retrieved from scatterometers and radiometers over the polar regions and its temporal coverage is from 2009 to now'.

Line 63: the word "geo-parameter retrieval" is not quite appropriate here.

Response: Thank you for the valuable comment. We rewrote the sentence as 'Optical imagery has been applied extensively in cryosphere observation'.

Line 65: "optical remote sensing data" should rewrite as optical imagery, check the whole manuscript.

Response: Thanks for the valuable comment, we have fixed the mistake.

Line 76-77: the sentence of "but the defect in which feature tracking cannot produce vectors…" is hardly comprehended. Please rephrase this sentence.

Response: Thank you for the valuable comment. We rewrote the sentence as 'The accuracy of their result is promising (Fang et al., 2023), but the spatial coverage needs to be further improved'.

Line 80-81: "However, it has been observed that the accuracy of the SID product with AVHRR is not good in s regions…"-Recheck this sentence

Response: Thank you for the valuable comment. We rewrote the sentence as 'However, it has been found that the accuracy of the SID product retrieved from AVHRR presents low accuracy in East Greenland, with the Mean Absolute Error (MAE) of velocity reaching 10.40 km/day, which is even lower than that of the SID products retrieved from radiometer and scatterometer (Wang et al., 2022)'.

Line 91-93: "Multiyear ice (MYI) drift…exist as drift ice"-Recheck this sentence.

Response: Thank you for the valuable comment. We rewrote the sentence as 'The multiyear ice (MYI) drifts from the Arctic basin and crushes in the central part of strait, which results in the fragmented ice in the southern part of the FS and along the eastern coast of Greenland'.

Line 95-99: "For our study, in comparison with other products, the retrieved SID from CZI images achieves good accuracy in the FS…" can be as the conclusions and do not put it here.

Response: Thank you for the valuable comment, we deleted these sentences in the introduction.

Line 98: "a sophisticated method was needed to retrieve the motion of drift ice", the sophisticated method should have references.

Response: Thank you for the valuable comment, we deleted the sentence to make the manuscript more readable.

Line 98: "The data enhancement process can aid our algorithm", the word "aid" is not quite appropriate here.

Response: Thank you for the valuable comment, we deleted the sentence due to inappropriate expression.

Line 110: "The wide swath and high resolution of CZI give us an opportunity to understand the sea ice motion in the FS in detail", the sentence is colloquial and need to refine.

Response: Thank you for the valuable comment. We rewrote the sentence as 'The wide swath and high spatial resolution of CZI imagery make it suitable for the sea ice motion observation in FS'.

Line 132-133: How about the validated result? it should be provided in the manuscript.

Response: Thank you for the valuable comment. For the uncertainty of SID product, we

check the CMEMS SID product user manual and find the validation of the product with ITP buoys. The number of matched pair is 29180, the correlation coefficient between the product and ITP buoys is 0.99, and RMSD of dx and dy is 362.32 m (0.0042 m/s) and 339.81 m (0.0039 m/s), the BIAS of dx and dy is 4.64 m and 17.29 m and the BIAS of velocity is negligible (~0 m/s). The time of validation is 2021 and the validation is performed with the 24-hour mean composite product. The validation shows very good correlation (almost 1.0) when tracking offsets are compared to a validation reference. Mean error values are very small, which indicates almost no bias, and the standard deviation of the differences is low. The validation proves that the CMEMS SID product has great accuracy. We added necessary descriptions about the validation in Section 2.2.

Line 134-135: "The CMEMS product with more overlay…"-Recheck this sentence.

Response: Thank you for the valuable comment. For the CMEMS SID product, the composite product is updated every 12 hours covering 24 hours. Thus, two kinds of product are provided, with a nominal time interval of 0:00 to 0:00 and 12:00 to 12:00, respectively. we rewrote the sentence as 'Therefore, the CMEMS SID product which has the most temporal overlap with CZI images is chosen for comparison'. In addition, we have added more descriptions of the CMEMS SID product.

Line 250: "The utilization of correlation coefficients and their derived parametric filtering and neighborhood filtering enhances the quality of the results", the word "enhances" is not quite appropriate here.

Response: Thank you for the valuable comment, we deleted the sentence due to inappropriate expression.

Line 259: In this study, higher-resolution SID fields are retrieved using CZI with a resolution of approximately 4 km while the grid resolution of the CMEMS SID product is 10 km. How the authors process the discrepancy of spatial resolution for the two products during the comparisons?

Response: Thanks for the valuable comment. We resampled our SID product from 4 km into 10 km with linear interpolation method. By resampling, our retrieval SID had the same spatial resolution as the CMEMS SID product. The necessary descriptions were added in the section 2.2.

Line 271: "…recovered SID…" – is it "retrieved SID"?

Response: Thanks for the valuable comment, we have changed the 'recovered' to 'retrieved'.

Line 283-284: "In our study, a small template is chosen considering the retrieved…less than 0.25m/s"-why a small template will result in this result, authors can illustrate the reasons.

Response: Thanks for the valuable comment. The size of the template and search area is associated with the spatial resolution of result. During the template matching, larger template size and search area means that the algorithm can find the maximum correlation point in wider area, but also it will lead to low-resolution result. The effect of template size and search area on retrieving SID will be explored in future research. We've rewritten the paragraph to make the expression clear. The following text was added to the manuscript.

The size of the template and search area is associated with the spatial resolution of result. To retrieve high spatial resolution SID in the FS, limited template size and search area is set in our study. Therefore, the maximum velocity of day-level result is lightly smaller than the product. The effect of template size and search area on retrieving SID will be explored in future research.

Line 320-321: "an RMSE" should be "a RMSE"

Response: Thanks for the valuable comment, we have changed all 'an RMSE' to 'a RMSE'.

Line 336: "combined with Table 4 and Table 5"-is it "Table 3 and Table 4"?

Response: Thanks for the valuable comment, we have fixed the mistake.

Line 391: Figure 14 shows the time interval of SAR images used for the CMEMS SID products while the legend in figure 14 shows day -level (CZI)? Please recheck it.

Response: Thanks for the valuable comment. In our study, the CZI dataset was divided into two different categories: hours-level and day-level. During comparing the result with the CMEMS SID product, discrepancies were identified with the hours-level result. The Figure 14 shows the corresponding time intervals of the CMEMS SID product in comparison and there is no obvious difference in the time interval between SAR images of the products used to compare with our results. The legend was modified to express our opinion clearly.

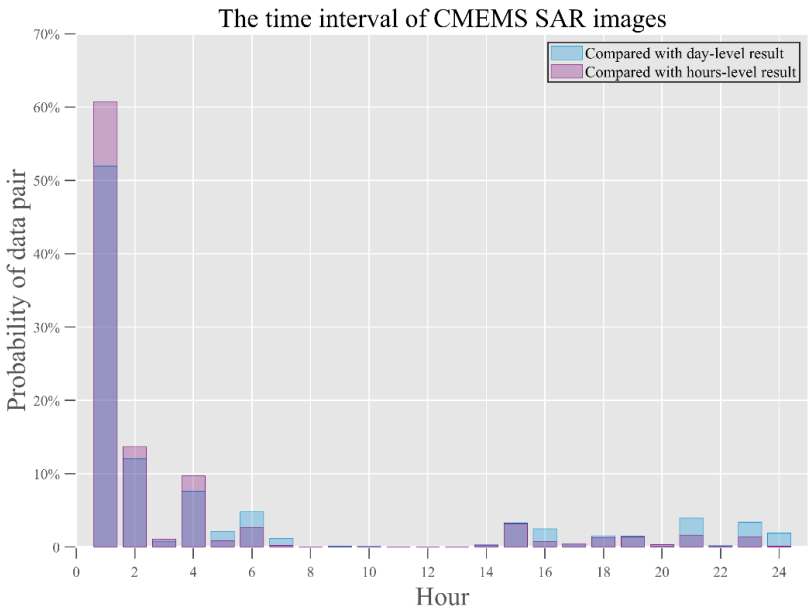

Figure 14: The time interval of SAR images used by the CMEMS SID product during the comparison with two different results.

The red line in Figure 18 is unnecessary.

Response: Thanks for the valuable comment, we deleted the red line.

Line 438: "As seen from the mean values, each quality … than for …"-the statement is incomplete.

Response: Thanks for the valuable comment, we have fixed the mistake. We rewrote the sentence as 'Each quality control parameter's mean value of the hours-level result is greater than that of the day-level result, which indicates that the hours-level result has the higher quality'.

Line 515: "Our method using the multi-template matching and subpixel estimation approach to retrieve SID in the FS produces a promising result. "a promising result" is not quite appropriate here.

Response: Thanks for the valuable comment, we rewrote the sentence as 'Our method, utilizing the multi-template matching and subpixel estimation approach for retrieving SID in FS, demonstrates great accuracy'.

Other comments:

The differences of quality control parameters in different regions of Fram Strait should be explained.

Response: Thanks for the valuable comment. The Fram Strait, where the sea ice changes dramatically, the sea ice in the southern and northern of the strait render different

morphologies in the images. Investigating the quality of retrieved SID in different regions associated with quality control parameters is valuable. The following text was added to the section 5.6 to discuss the quality control parameters in different regions.

The coherence between the quality control parameters and the validation of the buoys is illustrated in Fig. 21, providing a foundation for the meticulous examination of the SID quality. As one of the main outlets of Arctic sea ice in the Atlantic Ocean, the sea ice concentration in the FS is inferior than the Arctic Basin (Peng and Meier, 2018; Wang et al., 2020), and the sea ice in the south and north of the strait render different morphologies in the images.

To investigate the quality of SID over the strait, we selected 80°N as the segmentation line and calculated the quality control parameters of SID in north and south of the segmentation line. The Fig. 22 shows the stacking bars of different parameters in different regions. For the sake of visualization, we normalize the PMR and PSR. The average values of these quality control parameters indicate that SID in the north of 80° N have higher quality. Comparison of quality control parameters for results with different time intervals reveals that the hours-level result possesses higher quality. Besides, the hours-level result also has greater mean value of quality control parameters in the south of 80° N where the sea ice is dispersive. High-concentration sea ice constrains the variability of sea ice motion and provides better spatial consistency, which is beneficial for retrieving SID. Similarly, the variability of the sea ice motion with short time interval is inconspicuous, providing a favorable scene for the algorithm. The sea ice kinematics in marginal ice zone are intricate, and the effects of wave on the fragmentary sea ice motion are evident (Williams et al., 2013, p.1), which increases the uncertainty of retrieval. The utilization of short time interval images for SID retrieval proves instrumental in enhancing the quality of monitoring sea ice motion within marginal ice zones.

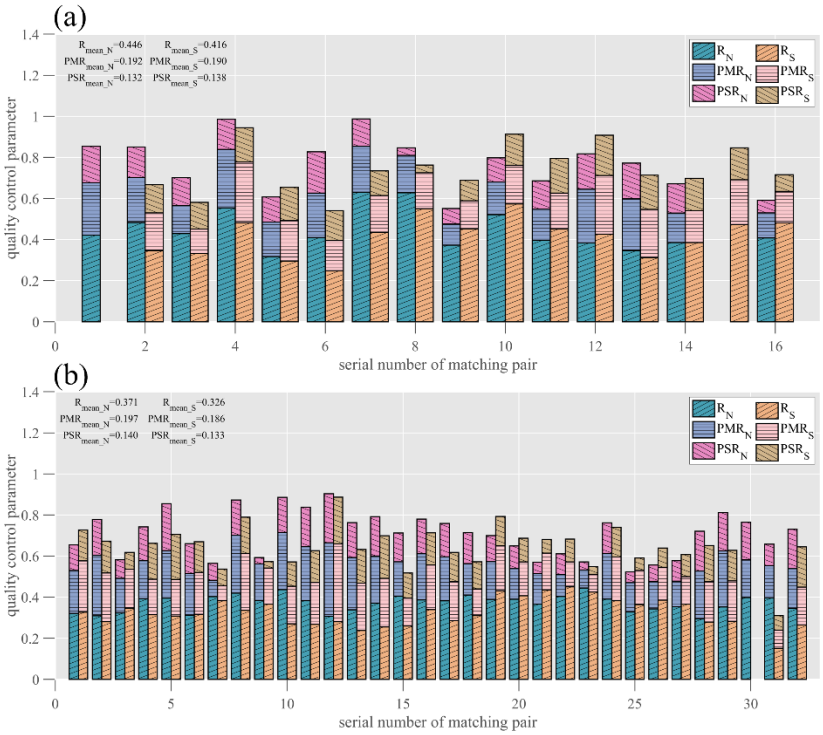

Figure 22: Statistics of quality control parameters for individual retrieval SID. (a: hours-level, b: day-level). The suffix N and S mean north and south of 80°N in FS.

The paper should introduce more detailed information about HaiYang series satellites and the level of data.

Response: Thanks for the valuable comment. The following text was added to the section 2.1 to introduce the Haiyang satellites and the level of data.

Since the launch of China's first ocean satellite in 2002, concerted efforts have been undertaken to institute a comprehensive global operational ocean satellite observation system. Currently, the observation system consists of 10 satellites, which include three series: ocean color series satellites (HY-1), ocean dynamic environment series satellites (HY-2), and ocean surveillance and monitoring series satellites (HY-3) (Zeng et al., 2023). In this paper, SID retrieval is performed using the L1C data which is processed with radiometric calibration and geographic projection. Before retrieving, the CZI images are resampled to 300 m considering the algorithm's computational efficiency and the spatial resolution of the result.

The relationship between drift distance and velocity retrieval accuracy should be explained.

Response: Thanks for the valuable comment. It is necessary to explore the relationship between the accuracy of the retrieval velocity and the distance of sea ice motion. We thus add a new section '5.5 Factors affecting the accuracy of velocity retrieval' to discuss how the distance and velocity of sea ice motion affect the retrieval accuracy of velocity in our study. The following text was added to the section 5.5.

Additionally, we delve into the correlation between the distance of sea ice motion and the accuracy of the retrieved velocity. A significant challenge to the accuracy of velocity retrieval, as emphasized by Lavergne, is the presence of quantification noise in template matching (Lavergne et al., 2010). Despite the acknowledged presence of quantification noise, our result surprisingly does not reveal its discernible effects, and a lack of a statistically significant correlation between the accuracy of the retrieved velocity and buoy distance is observed (As shown in Fig. 20).
Several explanations underpin this result. First, the spatial resolution of the resampled CZI imagery is 300m, which is a notable improvement for the ice surface feature observation compared to the kilometer-level resolution of radiometer. The higher spatial resolution is posited to be a key factor limiting the manifestation of quantification noise. The topographic features of sea ice are often quantified by the surface roughness and form drag (Arya, 1973, 1975) and those observed surface features have impact on ice drift speed (Zu et al., 2021). Unfortunately, the CZI imagery and resampled images are inadequate in detecting the topographic features. Second, the strong sea ice motion in FS renders sea ice dynamics distinctly visible in the image, indirectly suppressing the appearance of quantification noise. Finally, our application of subpixel estimation for the precise

localization of maximum correlation values, results in an exact determination of the maximum correlation location. This refinement contributes to improve the accuracy of retrieving SID. In conclusion, high spatial resolution data and subpixel estimation are able to suppress the negative effects caused by quantification noise.

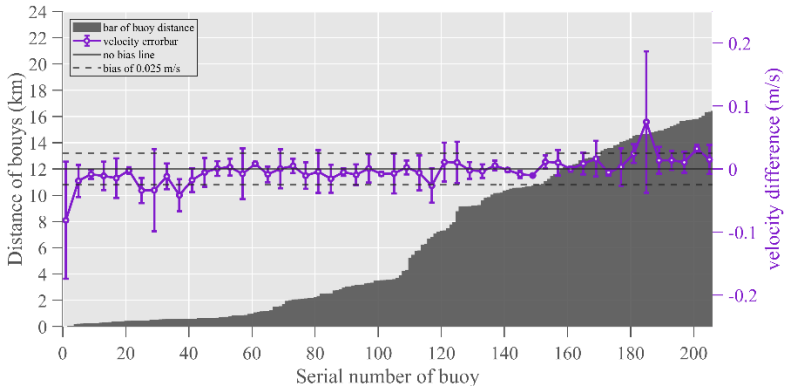

Figure 20: Relationship between the velocity difference and the displacement of the buoys.

Whether the time interval of images is appropriate for mosaicking images?

Response: Thanks for the valuable comment. CZI images from the same orbit are used for SID retrieval. Besides, we used images from different moments to find the intersection region and crop. Actually, we generated the dataset without mosaicking. We made necessary changes to the flowchart to correct the mistake in expression.

The study explored how the distance of sea ice motion affects the accuracy of flow direction retrieval, but the theory still not clear yet.

Response: Thanks for the valuable comment. The following text was added to the section 5.4 to illustrate how drift distance affects flow direction retrieval.

Due to stochastic error, the identification of the highest correlation point deviates to the optimal point. Consequently, the retrieved flow direction is constrained to the vicinity of the optimal point. The variability of flow direction retrieval with longer distance is more stable than with shorter distance.

As illustrated in the following figure, sea ice motion with longer distance (the blue vector) demonstrates better accuracy in flow direction retrieval compared to motion with shorter distance (the wheat vector).

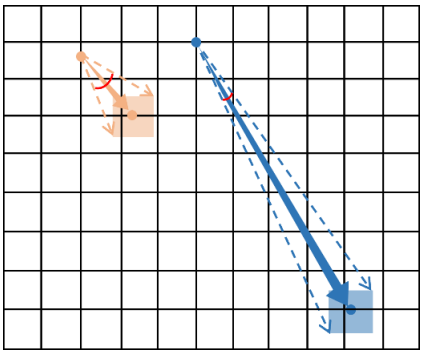

Figure: Illustration of how distance affects flow direction retrieval. Vectors with different color show the sea ice motion with different drift distance (wheat vector represent SID with short distance, blue vector with long distance), the square with color is the potential retrieval value, the small red curve is the potential range of retrieved flow direction.

Reference:

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Zeng, T., Shi, L., Huang, L., Zhang, Y., Zhu, H., and Yang, X.: A Color Matching Method for Mosaic HY-1 Satellite Images in Antarctica, Remote Sensing, 15, 4399, https://doi.org/10.3390/rs15184399, 2023.

Zu, Y., Lu, P., Leppäranta, M., Cheng, B., and Li, Z.: On the Form Drag Coefficient Under Ridged Ice: Laboratory Experiments and Numerical Simulations From Ideal Scaling to Deep Water, Journal of Geophysical Research: Oceans, 126, e2020JC016976, https://doi.org/10.1029/2020JC016976, 2021.