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RETRIEVAL OF SEA ICE DRIFT FROM THE CENTRAL ARCTIC TO THE FRAM STRAIT BASED ON SEQUENTIAL SENTINEL-1 SAR DATA

Yujia Qiu [1, 2] (qiuyujia20@mails.ucac.ac.cn), Xiao-Ming Li [3, 1] (lixm@radi.ac.cn)

[1] Key Laboratory of Digital Earth Science, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing, China

[2] University of Chinese Academy of Sciences, Beijing, China

[3] International Research Center of Big Data for Sustainable Development Goals, Beijing, China

ABSTRACT

This study focused on a comprehensive analysis of SID retrieval based on spaceborne synthetic aperture radar (SAR) data in the Arctic. A state-of-the-art method combining feature tracking and pattern matching techniques was applied to sequential Sentinel-1 (S1) SAR data to derive SID from the central Arctic to the Fram Strait in different seasons. The SAR retrievals were compared with drifting buoy data for validation. For temporal intervals of S1 data of 16 to 24 hours, 13,586 collocations were collected in the winter and spring seasons, yielding a 0.00 cm/s bias for the drift velocity magnitude and 0.32 degrees for direction with the corresponding root mean square error (RMSE) of 0.50 cm/s and 4.96 degrees. The applied method outperforms the maximum cross-correlation (MCC) method for rapidly drifting sea ice. Using temporal intervals of less than 16 hours, we retrieved SID in the summer and autumn seasons. 644 collocations yield a comparison with a bias of 0.52 cm/s and 4.62 degrees for the drift magnitude and direction, respectively. The corresponding RMSE values are 1.85 cm/s and 20.73 degrees. The comparisons present better results than the operational SAR-based SID product and consistent seasonal trends in drift velocity with the coarse-resolution product. We also analyzed the variations in SAR retrievals and further estimated appropriate temporal intervals, making it feasible to conduct long-term SID retrievals based on spaceborne SAR data at high spatial resolution in the Arctic.

INTRODUCTUION

Against the background of rapid Arctic sea ice retreat over the past decades, an accelerating trend of sea ice drift speeds has been observed. To better understand sea ice dynamics and support navigation safety, the high-resolution and stable-accuracy sea ice drift dataset is urgently needed. Spaceborne SAR monitoring the Arctic Ocean in all weather, day and night with high resolution is effective to retrieve sea ice drift. With the rise of computer vision technology, the combination of feature tracking and pattern matching shows great feasibility in the retrieval.

However, the retrieval accuracy also lies on temporal intervals between sequential SAR data. To date, relevant studies have not adequately considered the correlation between different temporal intervals and complicate sea ice conditions. Further comprehensive validation work remains to be accomplished to determine the applicability of the method in sea ice drift retrieval.

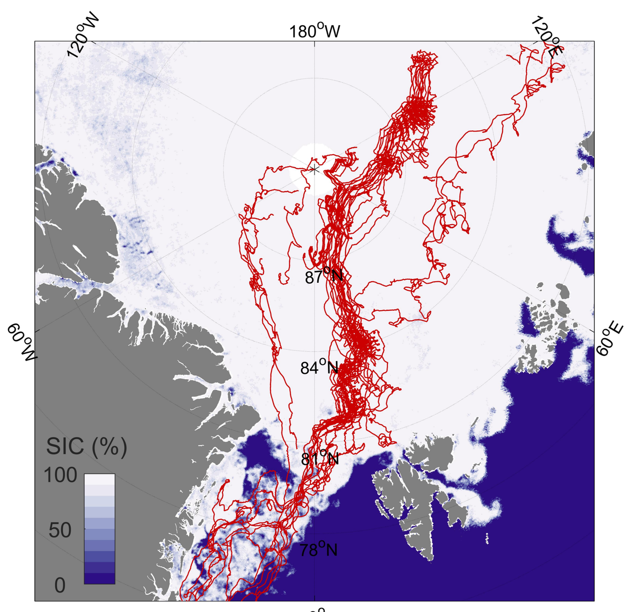
OBJECTIVES

a. Comprehensive sea ice drift retrieval in an area spanning from the central Arctic to Fram Strait from January to December 2020

b. Demonstrating the application of the state-of-the-art method combing the Feature Tacking and Pattern Matching for sea ice drift retrieval

c. Validating the SAR-retrieved sea ice drift vectors against the MOSAiC buoys

d. Investigating the uncertainties in seasons and temporal intervals



Study area with MOSAiC buoys

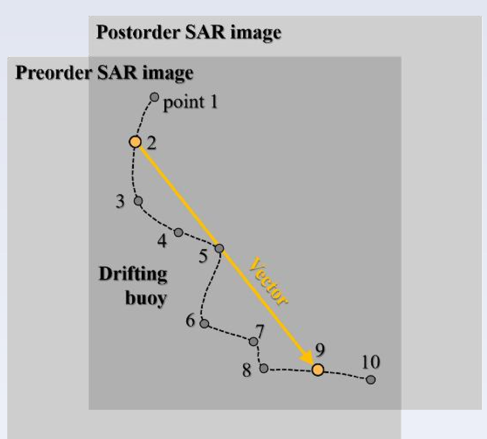
RESEARCH APPROACH

DATA used for retrieval: Sentinel-1A/B extra-wide swath data in HV polarization with a pixel size of 40 m × 40 m.

MOSAiC buoys used for validation.

Other sea ice drift products used for analysis:

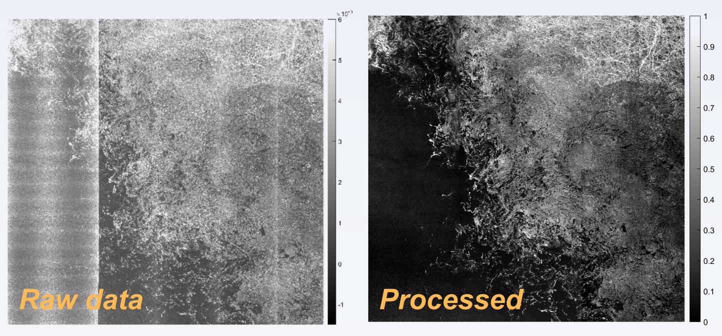
- SAR-based CMEMS products at 10 km resolution
- Radiometer-based OSI SAF products at 62.5 km resolution



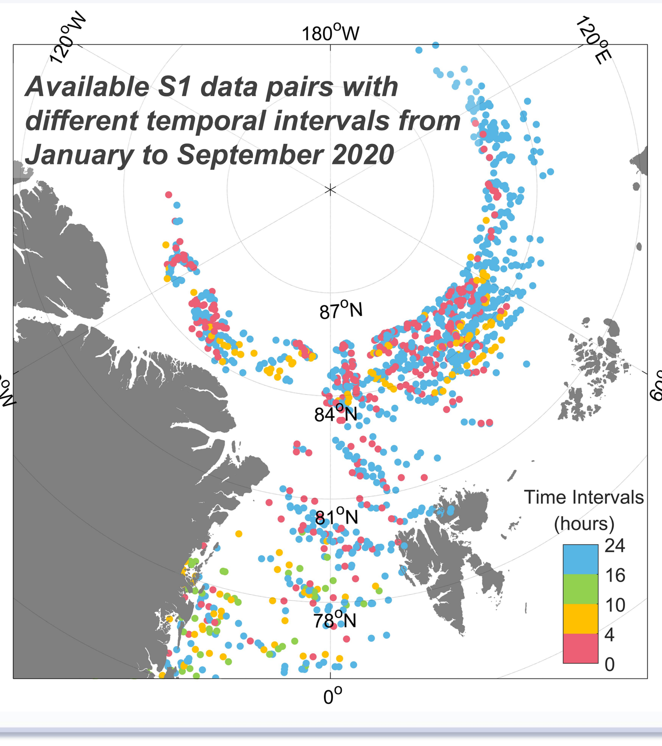
METHOD

SAR data processing:

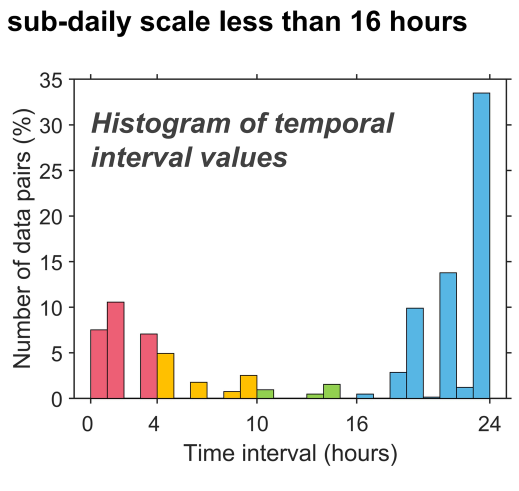
- Radiation calibration
- Removing residual noises
- Resampled to 200 m resolution



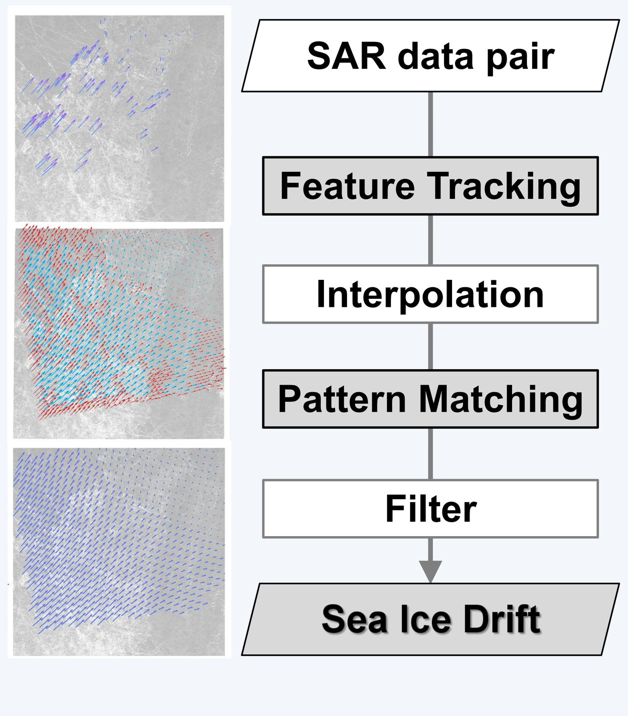
Matchup for sequential images:



- SAR data pairs with daily-scale intervals from 16 to 24 hours
- SAR data pairs with intervals in sub-daily scale less than 16 hours



Sea ice retrieval method combing the Feature Tracking and Pattern Matching

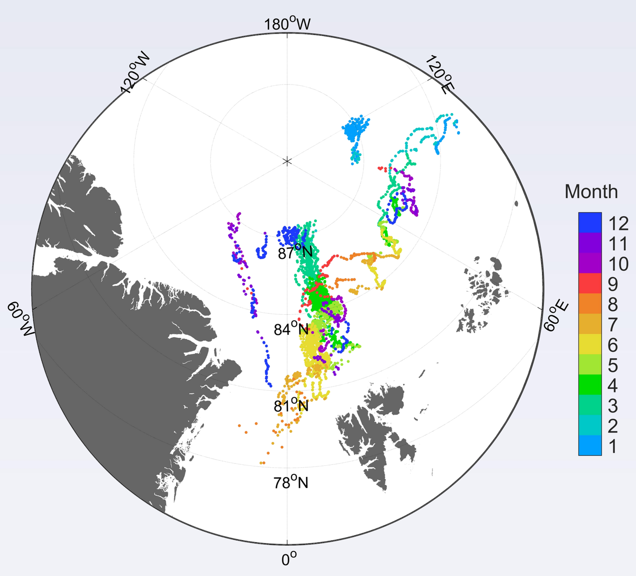


- Projection onto polar stereographic maps
- Tracking ORB features to find corresponding key points in data pairs
- Liner interpolation to generate the grids with initial displacements
- The MCC method to match templates with possible rotations
- Removing vectors with MCC coefficients < 0.4 or neighbouring differences > 10 km
- Sea ice drift velocity magnitude and direction in a 200 × 200 m grid

RESULT

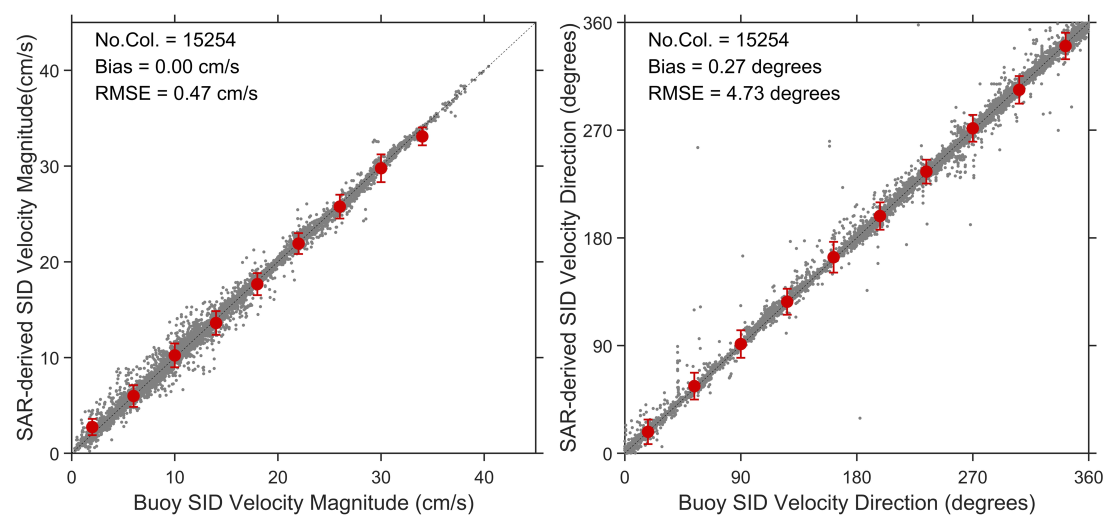
A total of 15,898 collocations of the buoy-computed and the SAR-derived sea ice drift vectors were obtained. However, due to sea ice melting in summer reducing detectable features, the summer retrieval applies SAR data with temporal intervals in sub-daily scales.

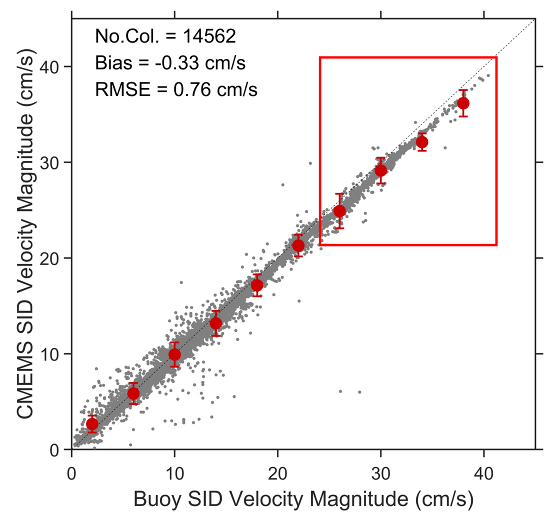
Consequently, from January to June and October to December 2020, 15,254 vectors based on 4,765 S1 data pairs with temporal intervals in daliy scales from 16 to 24 hours were collocated; between July and September 2020, 644 vectors based on 499 S1 data pairs with sub-daily scale intervals less than 16 hours were collocated.



SAR-derived vectors based on S1 data pairs with daily-scale temporal intervals

The statistical analysis shows that the retrieval has a bias of 0.00 cm/s and an RMSE of 0.57 cm/s for drift velocity magnitude and a bias of 0.27 degrees and an RMSE of 4.73 degrees for drift direction.

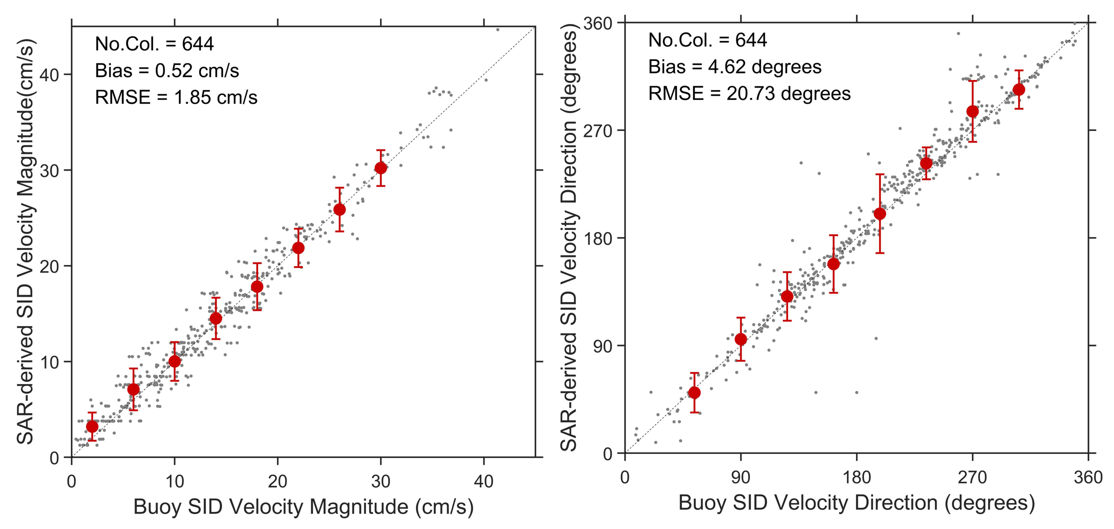




Comparing the validation of CMEMS products based on the same sources but produced by the MCC method against the buoys, its accuracy is lower than our result, with a bias of -0.33 cm/s and RMSE of 0.76 cm/s for the velocity magnitude. Also, the CMEMS data tend to underestimate the velocity above approximately 25 cm/s.

SAR-derived vectors based on S1 data pairs with sub-daily scale temporal intervals

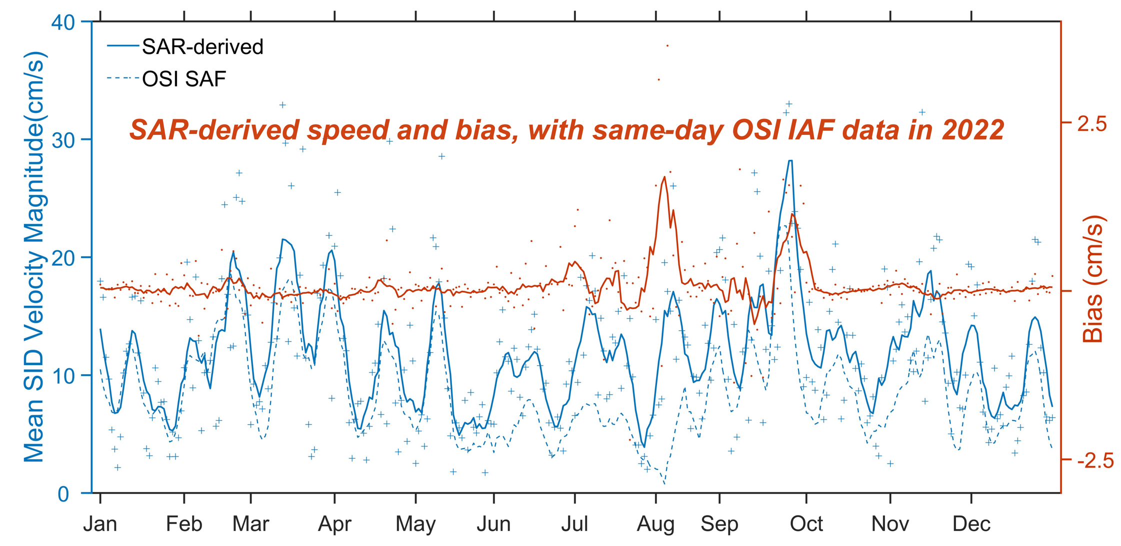
The comparisons of 644 collocations from July to September 2020 give a bias of 0.52 cm/s with an RMSE of 1.85 cm/s for drift velocity magnitude, and a bias of 4.62 degrees with an RMSE of 20.73 degrees for the drift direction.



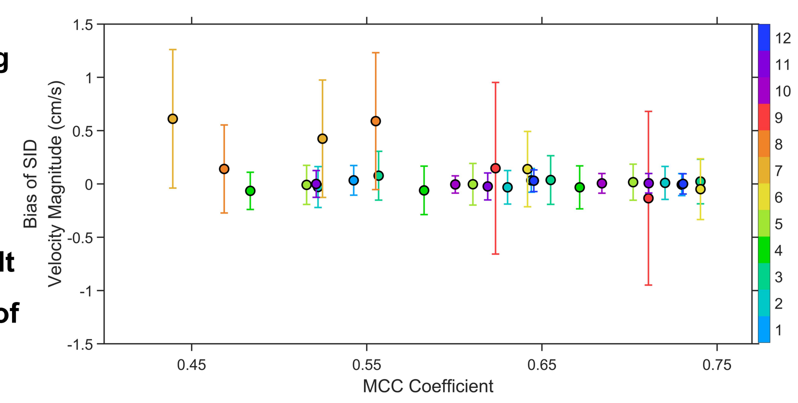
The error of retrieval by sub-daily intervals is larger than that by daily intervals. The primary reason is the difference in the collocation numbers (15,254 vs. 644). Another reason is the large temporal and spatial variability from July to September, strongly affecting the retrievals when interval changes.

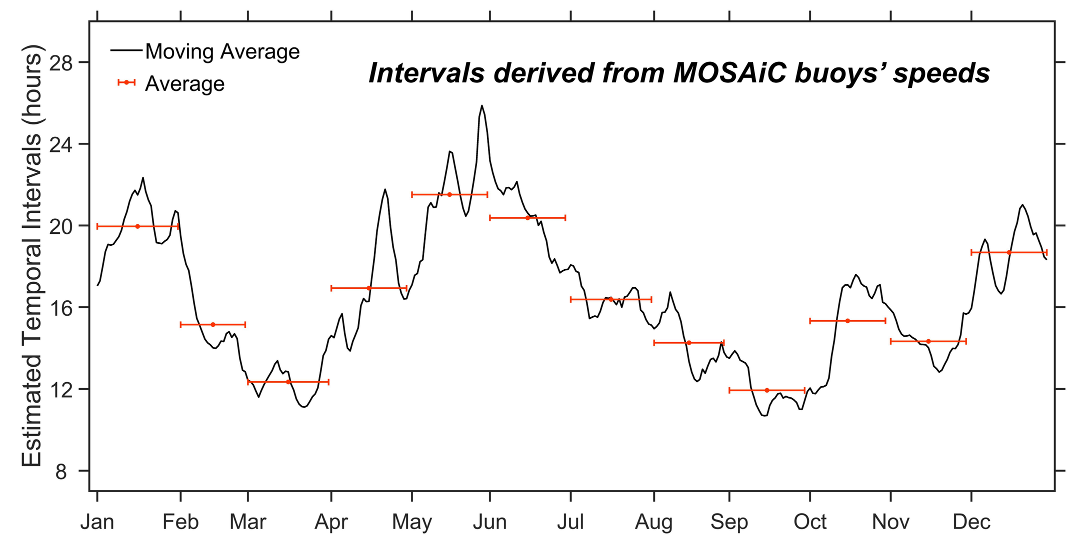
DISCUSSION

In general, the method well adapts to retrieving sea ice drift with high variability. However, the seasonal variations are evident. The maximum positive bias appears in August and reaches up to approximately 2.5 cm/s, accounting for 10% of the mean velocity magnitude in the same period.



The lower MCC coefficients in melting season than others suggest that the uncertainties from July and August result from the occurrence of ice decorrelation.





Based on an optimal distance for error convergence of 6.85 km, we applied the average speeds of MOSAiC buoys to derive the appropriate time intervals for different months. Considering the ice decorrelation, requirements for the months with low decorrelation can be relatively reduced. We recommend intervals above 20 hours for the months from January to June and October to December and intervals ranging from 12 hours to 16 hours for the remaining months from July to September.

SUMMARY

Inspired by computer vision techniques, a state-of-the-art method combining the Feature Tracking and Pattern Matching performs well in deriving sea ice drift from sequential SAR images. Based on our results of a year-round retrieval, we demonstrate the adaptability of the method to sea ice conditions with multivariable characteristics, presenting a consistent seasonal trend with the radiometer-based products, outperforming the CMEMS products based on the same SAR data. Our further investigation of retrieval uncertainty suggests that a high degree of ice decorrelation in the sea ice melting season leads to a decreased accuracy of retrieval. We also recommend appropriate temporal intervals to match sequential SAR data pairs for more accurate retrievals.

The spaceborne SAR satellites in the constellation bring better opportunities for obtaining sea ice drift at high spatial resolution in the Arctic than ever. However, the seasonal and spatial variability of sea ice pose challenges for retrieval. One of insights from this work is that appropriate time intervals are conducive to improving the retrieval accuracy. Future relevant studies and constellation designs could consider adopting these results. Particularly, while S1B was out of work sicnce December in 2021, S1C will be launched. We plan to process all the S1A and S1B data acquired thus far to provide insights into sea ice dynamics and their spatiotemporal variations at fine scales.

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