Research on the Arctic Sea-ice Type and Freeboard Detection Based on the Surface Waves Investigation and Monitoring Instrument of the China-French Ocean Satellite

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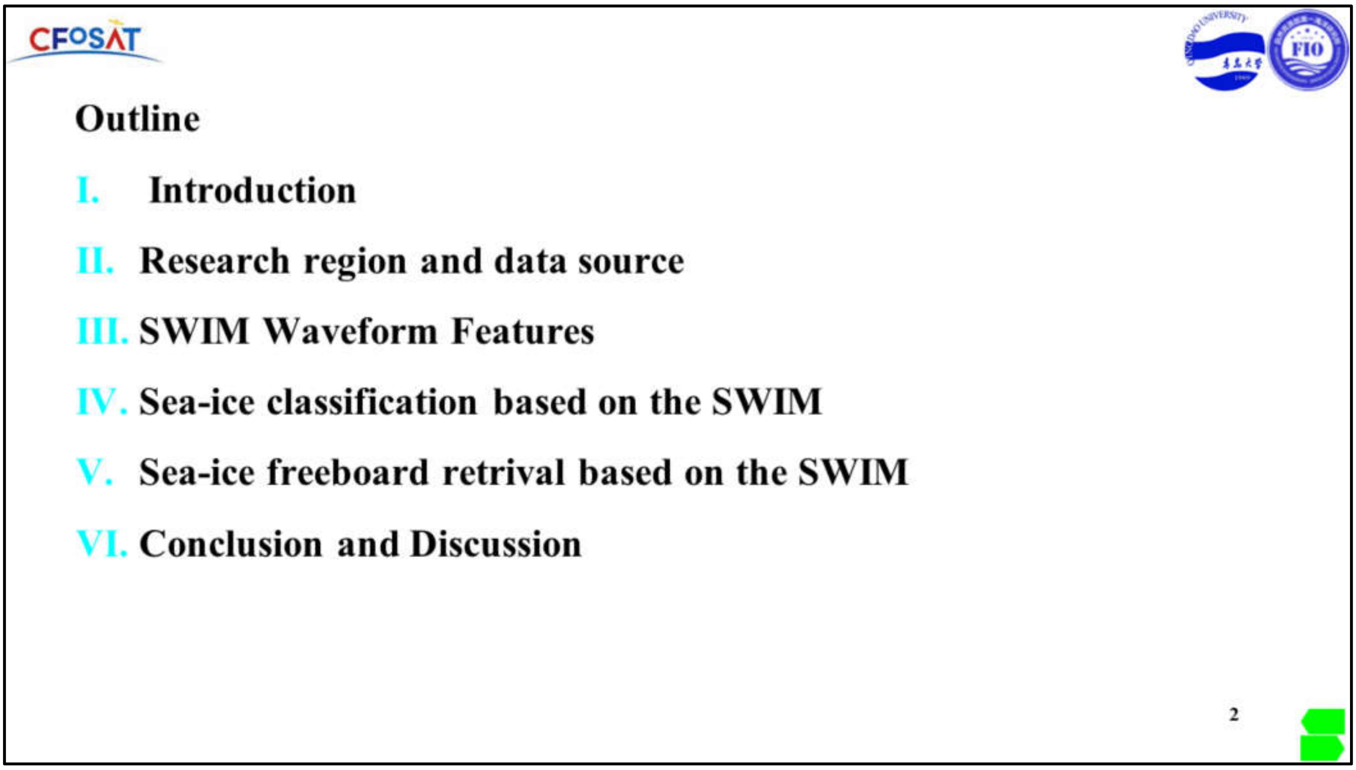
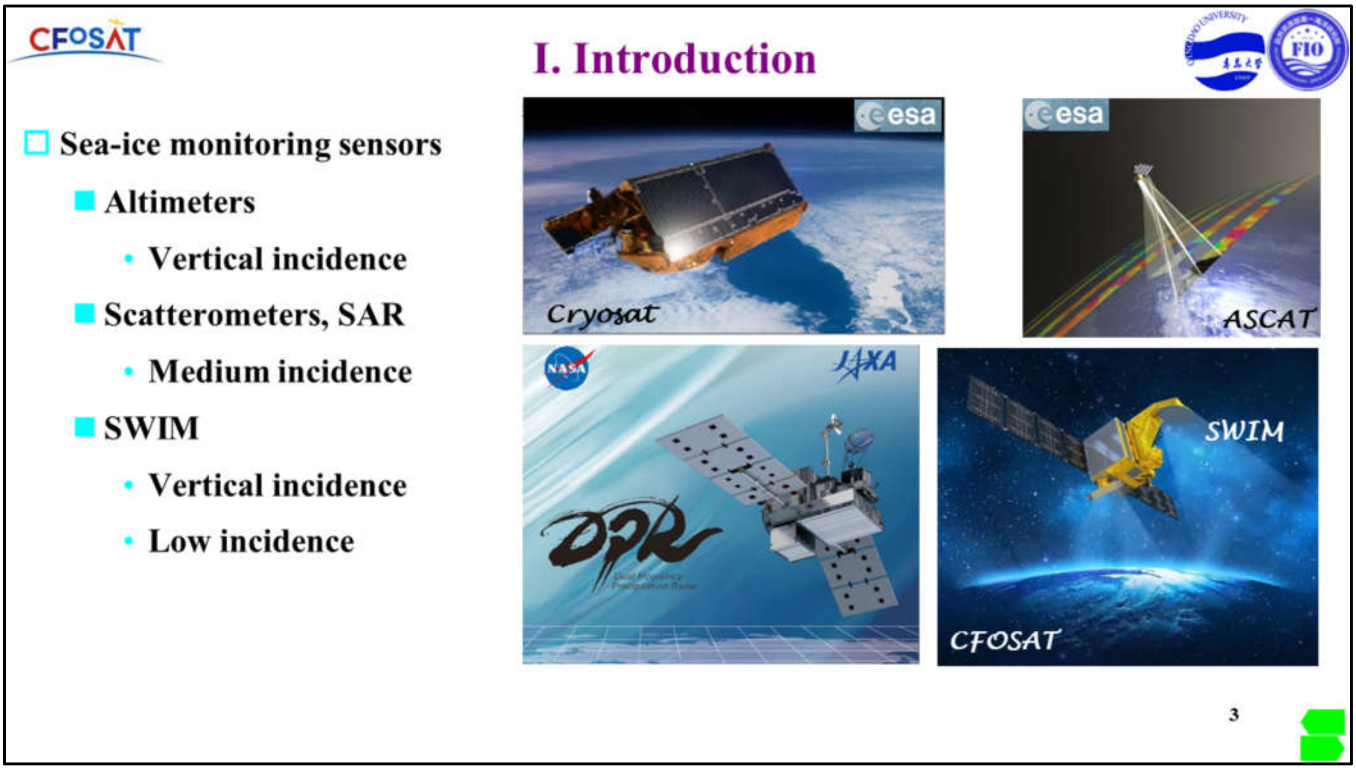


In this presentation, I mainly introduce our work in the sea-ice monitoring based on the SWIM data.



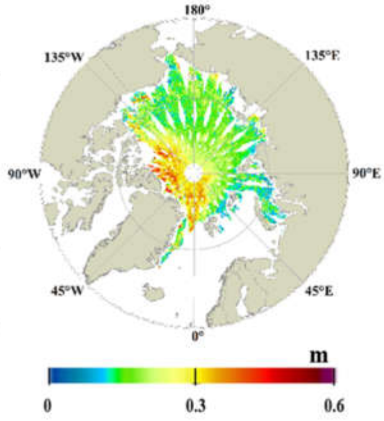
- The **sea-ice monitoring sensors** traditionally include the altimeter with the **vertical-incidence** mode of 0 degree, and the scatterometer and SAR with **medium incidence** mode of 20-60 degrees. The SWIM is a new sensor with the **vertical-incidence** mode and the **low incidence** mode (2°, 4°, 6°, 8°, 10°).
- **SWIM** covers the latitude range of 80° of the North and South, including the sea-ice regions in the Arctic and the Antarctic.
- It is wondered whether the SWIM with the low-incidence mode can detect the sea ice.

II. Research region and data source

We have been working on the sea-ice monitoring and research.

- **Research region**
  - **Arctic: the latitude is higher than 60°.**
  - **The Analysis of the sea-ice condition**
- **Data source**
  - **AARI: Sea-ice chart**
  - **Cryosat-2 L2I (CS2 L2I): Sea-ice freeboard**

Sea-ice chart of the AARI from January 5th to 7th, 2020



Cryosat-2 sea-ice freeboard in the Arctic

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Analysis of the sea-ice condition

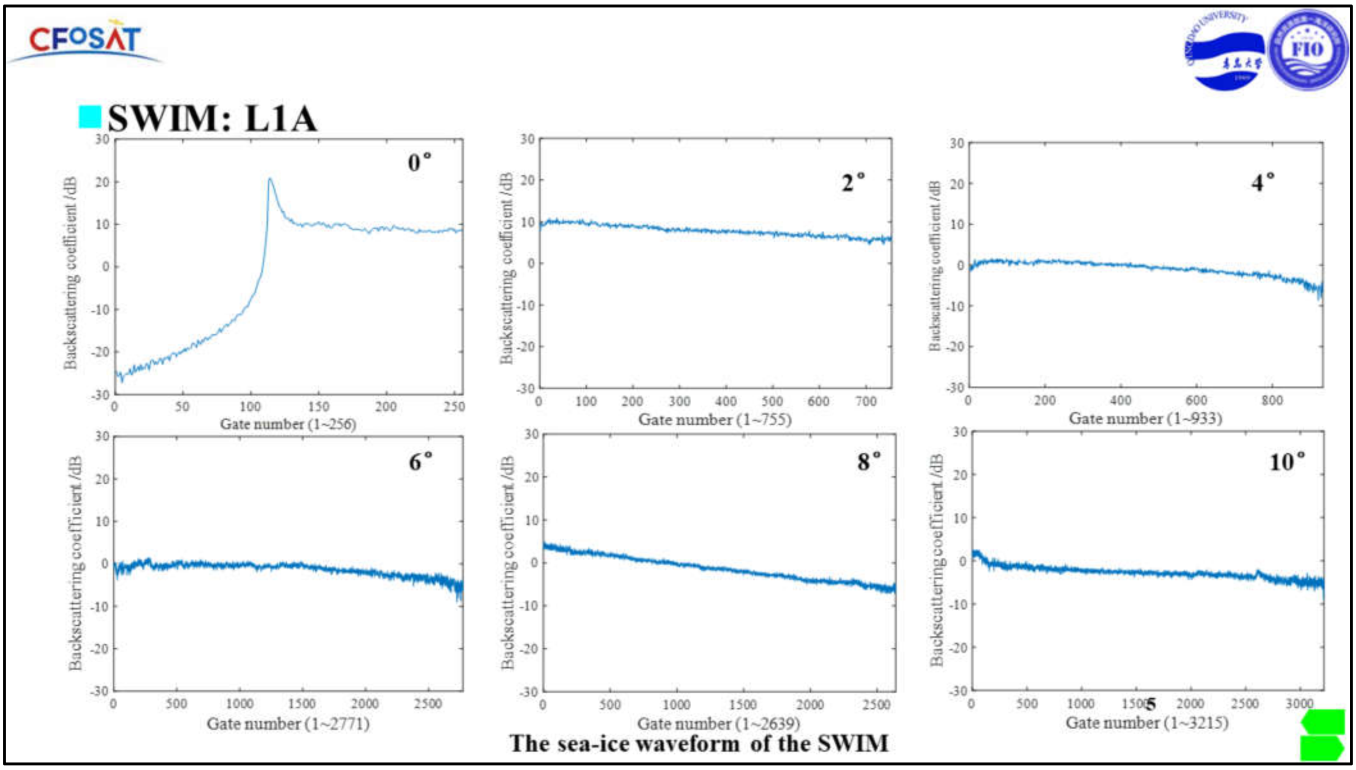
The first-year ice appears in the end of October, then develops rapidly through the November. The characteristic is unstable in the growing period.

The range of the multi-year ice is larger in the early November. The multi-year ice is covered with the snow from December leading to reducing its recognition accuracy.

AARI: State Scientific Center of the Russian Federation the Arctic and Antarctic Research Institute

AARI provided the sea-ice chart as the expert interpretation results of the sea-ice classification.

The sea-ice product of Cryosat-2 (CS2 L2I) provided the sea-ice freeboard as the standard results.



SWIM provided its L1A data with the waveform information.

III. SWIM Waveform Features

There were 11 waveform features extracted from SWIM L1A data in the different incidence angles, respectively, including:

- Feature 1 (F1): Azimuth angle
- Feature 2: Backscattering power
- Feature 3: Pulse peakiness
- Feature 4: Stack standard deviation
- Feature 5: IMP
- Feature 6: Leading edge width
- Feature 7: Trailing edge width
- Feature 8: Leading edge slope
- Feature 9: Trailing edge slope
- Feature 10: Stack kurtosis
- Feature 11: Skewness

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Feature was abbreviated to F.

IV. Sea-ice classification based on the SWIM

Sea-ice classification was studied using the SWIM waveform features in Arctic from 2019 to 2020. The recognition ability of the sea ice was studied with the low-incidence mode.

- **Accuracy evaluation of the sea-ice classification**
  - **Confusion Matrix:**
    - **Users accuracy (UA)**
    - **Producer accuracy (PA)**
    - **F1 Score (FS)**
    - **Overall accuracy (UA)**
  - **Kappa coefficient**

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Users accuracy was abbreviated to UA.
The change rule of the Kappa coefficient was consistent with that of the overall accuracy. Therefore, the overall accuracy was used to analyze the classification result.

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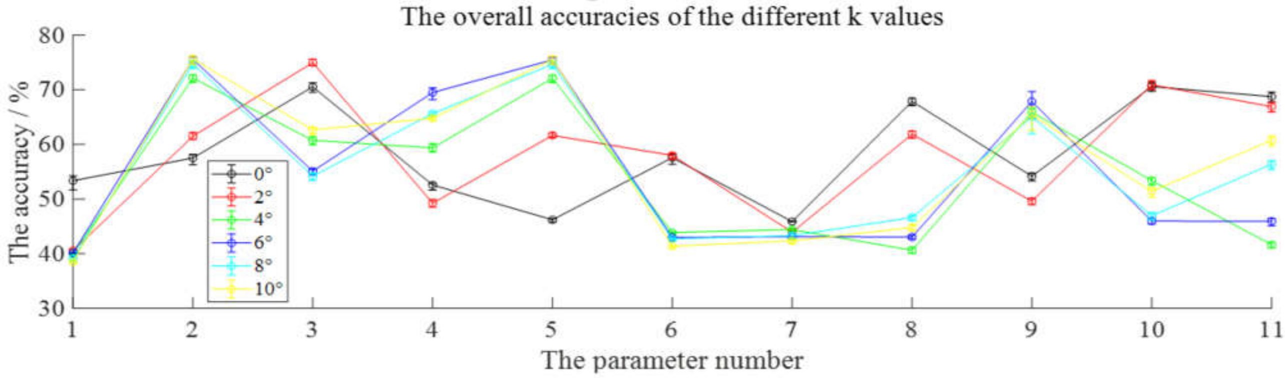
K-value test of the K-Nearest-Neighbor method



- **The k-value range was from 3 to 7.**
- **The k value of the KNN method had little influence on the the overall accuracies of the sea-ice classification.**
- **The k value was chosen the value of 3.**

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The k vaule usually had the effect on the classification results. In the test, the k-value range of the sea-ice classification was from 3 to 7. In the figure, the small circle represented the mean overall accuracy value calculated through the five k values. The short line above the small circle represented the maximal overall accuracy value calculated through the five k values, and The short line below the small circle represented the minimal overall accuracy value calculated through the five k values. It is shown that the change of the overall accuracy caused by the k value was little. Therefore, the k value of the KNN method had little influence on the the overall accuracies of the sea-ice classification. In our work, the k value was chosen the value of 3.

Sea-ice classification by the single feature

There were three sea-ice types including the first-year ice (FY), the multi-year ice (MY), and the sea water (SW). There were 25 sea-ice charts announced by AARI from November, 2019 to April, 2020. The SWIM L1A data matched the sea-ice charts synchronously in time and space to construct 25 sea-ice groups. The classification method was K Near Neighbor (KNN).

Selection criteria of the optimal single features:

- The top four features for the F1 scoreas of the different types and the overall accuracies of the all types.
- If the F1 scores or the overall accuracies of the rest features were higher than 70%, the features were also chosen.

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Type \ Feature		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
FY / %	UA	50.6	62.5	66.0	59.3	53.0	53.0	47.1	65.6	59.0	66.2	65.3
	PA	92.3	71.8	71.5	70.9	66.1	99.7	99.9	71.7	71.9	72.3	71.5
	FS	64.9	66.8	68.6	64.5	58.7	68.5	63.1	68.5	64.8	69.0	68.2
MY / %	UA	61.7	34.9	48.1	36.1	40.2	4.5	32.4	44.6	33.7	48.4	45.0
	PA	21.4	26.4	42.2	27.4	32.3	0.5	0.2	37.4	25.5	42.0	38.1
	FS	30.9	29.9	44.8	31.0	35.7	0.9	0.4	40.6	28.9	44.8	41.1
SW/ %	UA	91.9	59.0	97.5	46.4	32.9	97.9	69.2	86.4	48.9	97.1	93.6
	PA	16.3	58.8	95.2	41.5	24.5	36.4	0.4	86.9	41.5	94.1	92.9
	FS	27.3	58.8	96.4	43.7	27.8	52.5	0.8	86.6	44.7	95.6	93.3
OA / %		54.5	57.8	70.8	53.5	48.3	55.9	47.1	67.5	53.4	70.8	69.0

- For the three types, the optimal multi-feature sets were F3, F8, F10 and F11 which agreed with the overall accuracies.

- The optimal multi-feature sets were marked by the yellow color.
- Every accuracy in the table was averaged by the classification results of 25 sea-ice sample groups.

■2°

Type \ Feature		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
FY / %	UA	45.4	58.9	68.6	55.4	58.9	52.7	45.6	61.2	55.5	65.3	64.3
	PA	79.2	63.6	74.2	68.5	63.8	99.4	98.7	69.8	69.2	71.4	70.7
	FS	57.6	61.1	71.3	61.2	61.2	68.2	61.8	65.2	61.5	68.2	67.3
MY / %	UA	29.1	42.3	55.2	34.4	42.4	6.9	8.2	40.0	37.3	48.5	42.7
	PA	16.2	37.2	49.9	27.8	37.1	0.3	0.5	33.8	30.3	42.6	35.6
	FS	19.6	39.5	52.3	30.5	39.5	0.6	1.0	36.5	33.2	45.3	38.7
SW/ %	UA	25.7	88.5	97.8	41.0	88.5	97.6	62.0	78.9	43.4	95.3	85.5
	PA	4.6	87.9	93.7	32.5	87.9	52.7	1.2	72.8	32.9	92.1	86.6
	FS	7.4	88.2	95.7	36.1	88.2	68.3	3.1	75.7	37.3	93.7	86.0
OA / %		44.2	63.9	73.8	49.6	63.9	58.9	45.6	62.1	50.6	70.2	66.4

- **For the three types, the optimal multi-feature sets were F3 and F10 which were the highest overall accuracies.**

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Type \ Feature		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
FY / %	UA	45.0	66.6	60.1	58.0	66.6	45.4	45.6	47.1	59.9	55.7	48.8
	PA	77.4	71.4	67.8	63.5	71.4	97.7	97.5	60.3	81.7	63.5	60.6
	FS	56.9	68.9	63.7	60.6	68.9	61.3	61.4	52.7	69.1	59.2	53.9
MY / %	UA	29.2	52.8	41.6	40.3	52.8	14.8	14.0	30.9	48.3	35.4	30.8
	PA	16.7	47.8	35.3	33.7	47.9	0.5	0.6	23.1	21.4	27.8	23.1
	FS	20.1	50.1	38.1	36.6	50.1	1.0	1.0	26.2	27.8	30.9	26.2
SW/ %	UA	26.1	95.3	84.3	78.6	95.3	51.9	55.7	35.4	87.1	64.8	34.4
	PA	5.9	92.9	78.9	80.1	92.8	4.5	5.8	27.3	87.7	64.0	29.1
	FS	9.2	94.0	81.4	79.3	94.0	8.2	10.5	30.1	87.4	64.2	30.9
OA / %		43.7	71.7	63.0	60.7	71.7	45.6	45.9	43.0	67.8	55.1	43.8

- **For the three types, the optimal multi-feature sets were F2, F3 and F5 which agreed with the overall accuracies.**

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■ 6°

Type \ Feature		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
FY/ %	UA	45.1	69.8	55.1	65.0	69.8	45.3	45.5	50.8	58.2	51.2	53.4
	PA	77.8	73.0	63.0	67.6	72.9	94.3	93.8	63.5	90.7	59.0	62.0
	FS	57.1	71.3	58.6	66.2	71.3	60.6	60.7	56.2	70.6	54.6	57.1
MY/ %	UA	29.2	57.8	37.2	51.2	57.8	21.7	20.5	31.6	45.8	33.0	31.2
	PA	16.8	53.6	32.1	46.1	53.7	2.6	2.8	24.4	7.5	27.1	25.6
	FS	20.0	55.5	34.2	48.4	55.6	4.4	4.7	27.1	12.2	29.5	27.8
SW / %	UA	25.3	97.5	74.0	90.0	97.5	34.1	37.5	44.5	86.8	48.2	43.9
	PA	5.2	96.9	65.0	93.3	96.8	3.3	4.5	35.0	88.7	43.6	39.0
	FS	8.0	97.2	69.0	91.6	97.2	6.0	7.8	38.8	87.8	45.6	41.0
OA / %		44.2	75.0	56.6	69.7	75.0	45.0	45.2	47.1	66.7	48.1	47.7

- **For the three types, the optimal multi-feature sets were F2, F4 and F5 which were the highest overall accuracies.**

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8°

Type \ Feature		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
FY / %	UA	44.5	69.7	56.9	61.9	69.7	44.8	45.1	51.5	56.5	52.8	58.2
	PA	76.7	73.1	66.1	65.6	73.0	94.7	94.2	64.4	89.4	60.5	64.0
	FS	56.3	71.3	61.1	63.6	71.3	60.1	60.4	57.1	68.9	56.3	60.9
MY / %	UA	29.5	59.4	34.7	47.4	59.3	27.0	24.3	34.0	35.3	32.6	37.9
	PA	18.0	55.0	29.5	42.2	55.2	4.0	4.2	26.1	5.9	27.6	32.1
	FS	21.3	57.1	31.7	44.5	57.1	6.7	6.8	29.2	9.9	29.5	34.6
SW / %	UA	25.9	97.4	64.8	92.0	97.4	35.9	40.8	56.6	84.0	48.6	70.3
	PA	5.1	96.2	57.4	93.8	96.1	1.9	3.3	46.0	82.5	44.0	70.1
	FS	8.2	96.8	60.9	92.9	96.8	3.5	6.0	50.7	83.2	46.1	70.2
OA / %		43.3	75.6	54.8	68.1	75.5	44.5	44.8	50.6	64.0	48.6	58.1

- For the three types, the optimal multi-feature sets were F1, F4 and F5 which were the highest overall accuracies.

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Feature / Type		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
FY / %	UA	43.5	70.2	62.8	59.9	70.2	44.0	44.4	49.0	56.2	54.9	59.1
	PA	76.4	73.6	71.5	64.9	73.5	94.9	94.4	65.0	92.4	63.8	64.2
	FS	55.4	71.8	66.9	62.2	71.8	59.4	59.8	55.8	69.4	59.0	61.5
MY / %	UA	30.2	62.1	41.1	46.2	62.0	26.2	24.7	34.0	35.7	33.7	42.3
	PA	18.3	57.5	33.6	40.2	57.7	3.4	3.6	24.0	4.2	26.2	36.1
	FS	21.6	59.6	36.9	42.8	59.7	5.7	5.9	27.9	7.3	29.4	38.8
SW / %	UA	27.4	97.5	77.2	93.2	97.5	41.0	47.6	55.6	87.4	56.2	79.5
	PA	5.8	96.5	75.0	93.8	96.5	3.9	6.2	43.7	85.2	54.9	81.2
	FS	9.1	97.0	76.1	93.5	97.0	7.1	10.8	48.9	86.3	55.5	80.3
OA / %		42.9	76.8	62.9	67.5	76.7	43.9	44.4	49.4	64.9	52.2	62.4

- For the three types, the optimal multi-feature sets were F2 and F5 which were the highest overall accuracies.

Above all, for the first-year ice, PA>FS>UA; For the multi-year ice, UA>FS>PA; For the sea water, UA>FS>PA.

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Sea-ice classification by the multi-feature sets

For every incidence angle, 12 multi-feature sets with the highest overall accuracies in every data group were selected, and the 300 multi-feature sets were sorted by the occurrence numbers of their overall accuracies, then the 12 highest multi-feature sets were selected as the optimal sets.

0°		2°		4°		6°		8°		10°	
Feature set	Occurrence number	Feature set	Occurrence number	Feature set	Occurrence number	Feature set	Occurrence number	Feature set	Occurrence number	Feature set	Occurrence number
[1,3,4,6,7,9,10,11]	14	[2,4,8,9]	25	[2,3,4,10,11]	12	[2,3,4,8,10,11]	12	[2,3,4,8,10,11]	10	[2,3,4,8,10,11]	11
[1,3,4,6,7,10,11]	13	[2,4,5,8,9]	25	[2,3,4,5,9,10,11]	12	[2,4,8,9,10,11]	12	[2,3,4,5,8,10,11]	9	[2,3,4,9,10,11]	11
[1,2,3,4,6,7,10,11]	13	[2,4,8]	24	[2,3,4,5,10,11]	11	[2,4,5,8,9,10,11]	12	[2,3,4,8,11]	8	[2,3,4,5,8,10,11]	11
[1,3,4,5,6,7,10,11]	12	[2,4,5,8]	24	[2,3,4,9,10,11]	11	[2,3,4,5,8,10,11]	11	[2,3,4,5,8,11]	8	[2,3,4,5,9,10,11]	11
[1,3,4,6,7,8,10,11]	12	[2,4,6,8,9]	24	[2,3,4,8,11]	9	[2,3,4,8,9,10,11]	11	[2,4,9,10,11]	7	[2,3,4,8,9,10,11]	11
[1,2,3,4,6,7,9,10,11]	12	[2,4,5,6,8,9]	24	[2,3,4,5,8,11]	9	[2,3,4,5,8,9,10,11]	11	[2,4,5,9,10,11]	7	[2,3,4,5,8,9,10,11]	11
[1,3,4,6,7,8,9,10,11]	12	[2,4,6,8]	23	[2,3,4,8,9,11]	9	[2,3,4,10,11]	9	[2,4,8,9,11]	6	[2,4,5,9,10,11]	10
[1,2,3,4,5,6,7,10,11]	11	[2,4,5,6,8]	23	[2,3,4,8,10,11]	9	[2,4,8,10,11]	9	[2,3,4,8,9,11]	6	[2,4,8,9,10,11]	10
[1,2,3,4,6,7,8,10,11]	11	[2,4,5,9]	7	[2,3,4,5,8,9,11]	9	[2,3,4,5,10,11]	9	[2,4,5,8,9,11]	6	[2,4,5,8,9,10,11]	10
[1,3,4,5,6,7,8,10,11]	11	[2,4,6]	5	[2,3,4,8,9,10,11]	9	[2,4,5,8,10,11]	9	[2,4,8,9,10,11]	6	[2,4,9,10,11]	9
[1,3,4,5,6,7,9,10,11]	11	[2,4,9]	5	[2,3,4,5,8,9,10,11]	9	[2,3,4,9,10,11]	6	[2,3,4,5,8,9,11]	6	[2,4,10,11]	8
[1,2,3,4,5,6,7,8,10,11]	11	[2,4,6,9]	5	[2,3,4,5,8,10,11]	8	[2,4,10,11]	5	[2,3,4,8,9,10,11]	6	[2,3,4,10,11]	8

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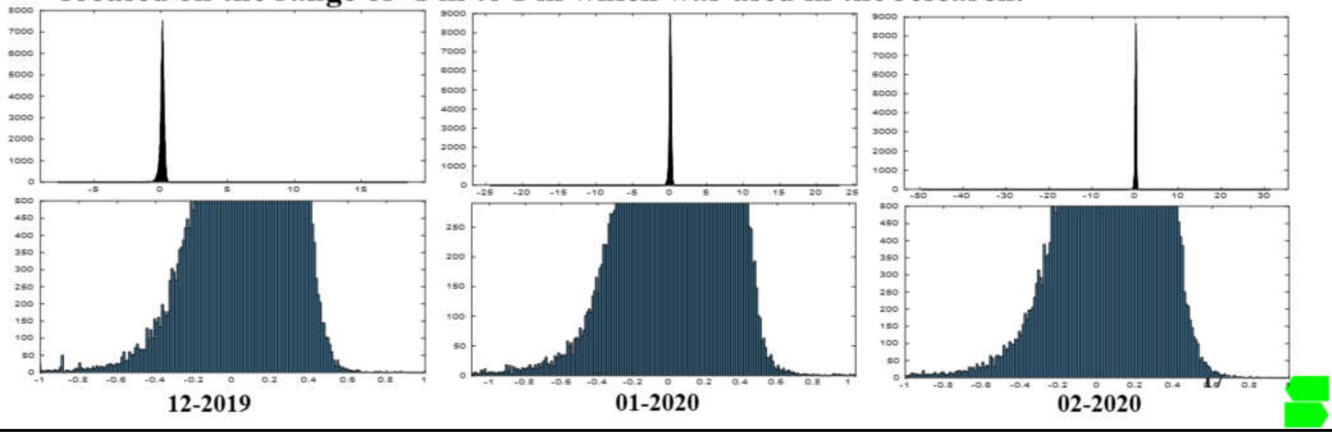
V. Sea-ice freeboard retrival based on the SWIM

Sea-ice freeboard responding to the waveform features retrival was studied using the SWIM data in the Arctic from 2019 to 2020.

□ Sea-ice freeboard range

Although the sea-ice freeboard of CS2 L2I varied in the wide range, the values mainly focused on the range of -1 m to 1 m which was used in the research.



The x axis represented the values of the sea-ice freeboard (unit: m), and the y axis represented the occurrence numbers of the values of the sea-ice freeboard.

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Sea-ice freeboard retrival using the BPNN based on the SWIM

- **The SWIM L1A data and the CS2 L1I data which was from December 2019 to February 2020 were matched synchronously in time and space.**
- **Sea-ice freeboard was retrieved using the Back Propagation Neural Network (BPNN).**
- **All of the 11 waveform features derived from the SWIM L1A data were used to construct the net of the BPNN.**
- **The matching data was divided into two sets, one for training the net and the other for verifying the net verification.**
- **The values of the two sets were segmented in 0.1 m, and the values of the 11 SWIM features in every segment of the freeboard height were averaged.**

Sea-ice freeboard retrival results

12-2019

Angle / Error	0°	2°	4°	6°	8°	10°
CC / m	0.96	0.94	0.95	0.95	0.95	0.86
MAE / m	0.13	0.16	0.14	0.18	0.17	0.26
RMSE / m	0.17	0.21	0.19	0.20	0.20	0.34
MRE	0.34	0.35	0.31	0.46	0.47	0.51

01-2020

Angle / Error	0°	2°	4°	6°	8°	10°
CC / m	0.98	0.99	0.95	0.95	0.91	0.94
MAE / m	0.11	0.08	0.14	0.12	0.16	0.15
RMSE / m	0.14	0.11	0.20	0.19	0.25	0.21
MRE	0.29	0.17	0.23	0.29	0.36	0.41

02-2020

Angle / Error	0°	2°	4°	6°	8°	10°
CC / m	0.67	0.98	0.95	0.92	0.92	0.91
MAE / m	0.23	0.10	0.15	0.15	0.17	0.17
RMSE / m	0.47	0.14	0.23	0.25	0.23	0.25
MRE	0.35	0.26	0.27	0.32	0.42	0.35

CC : correlation coefficient
MAE: man absolute error
RMSE: root mean square error
MRE: mean relative error

VI. Conclusion and Discussion

- Conclusion
  - The optimal classification features of the SWIM L1A waveforms were analied.
  - The optimal feature sets for the sea-ice classification were selected.
  - The potential of the SWIM L1A waveform features were studied.
- Discussion
  - Sea ice types will be classified by the multiple features and the multiple incidence angles.
  - Sea-ice thickness will be retrieved based on the SWIM.

That is all.