# Sea ice type classification and snowmelt onset detection in the polar region based on CFOSCAT data

**Rui Xu[1], Chaofang Zhao[1, 2], Christian Haas[3], Stefanie Arndt[3], Xiaochun Zhai[4]**

[1]Ocean University of China, Qingdao, China

[2]Laboratory for Regional Oceanography and Numerical Modeling, Qingdao National Laboratory for Marine Science and Technology, Qingdao, China

[3]Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany

[4]National Satellite Meteorological Center, Beijing 100081, China

# Background

First-year ice (FYI) and multi-year ice (MYI) are the two most common ice types in the Arctic. MYI has a higher albedo compared with FYI, and also is a good proxy for the ice thickness, thereby influencing energy fluxes and serves as an indicator to climate forcing. Therefore, the discrimination of MYI is of great significance.

As a Ku-band scatterometer, QuikSCAT has significantly contributed to sea ice studies in the polar region. However, the end of its life span means that a new replacement is needed to continue the study of the Ku-band scatterometer in polar sea ice monitoring. We therefore retrieved FYI and MYI by combining the data of CFOSCAT and passive microwave sensors based on Tree Augmented Naive Bayes algorithm. However, in the Antarctic, there is not as much MYI as in the Arctic. Snow on the Antarctic sea ice is one of the reasons that makes the identification of MYI more difficult. The thicker snow cover on the Antarctic MYI compared with Arctic typically survive throughout the summer and makes the role of snow on Antarctic sea ice is particularly important to sea ice classification. We therefore used CFOSCAT and ASCAT to study snowmelt processes on MYI ice to improve our understanding of the interaction between snow and active microwave signal, which will help improve the identification of MYI in the Antarctic.

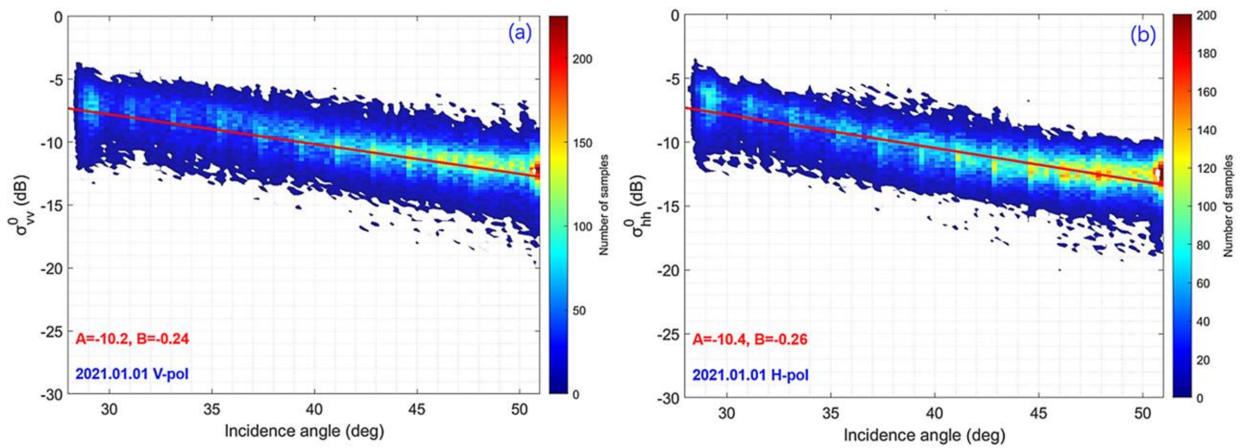
# Contents

POLAR

- Sea ice classification by combining CFOSCAT and AMSR2 data in the Arctic
- Snowmelt onset on MYI in the Antarctic observed by CFOSCAT and ASCAT
- Summary

# Sea ice classification-Dataset

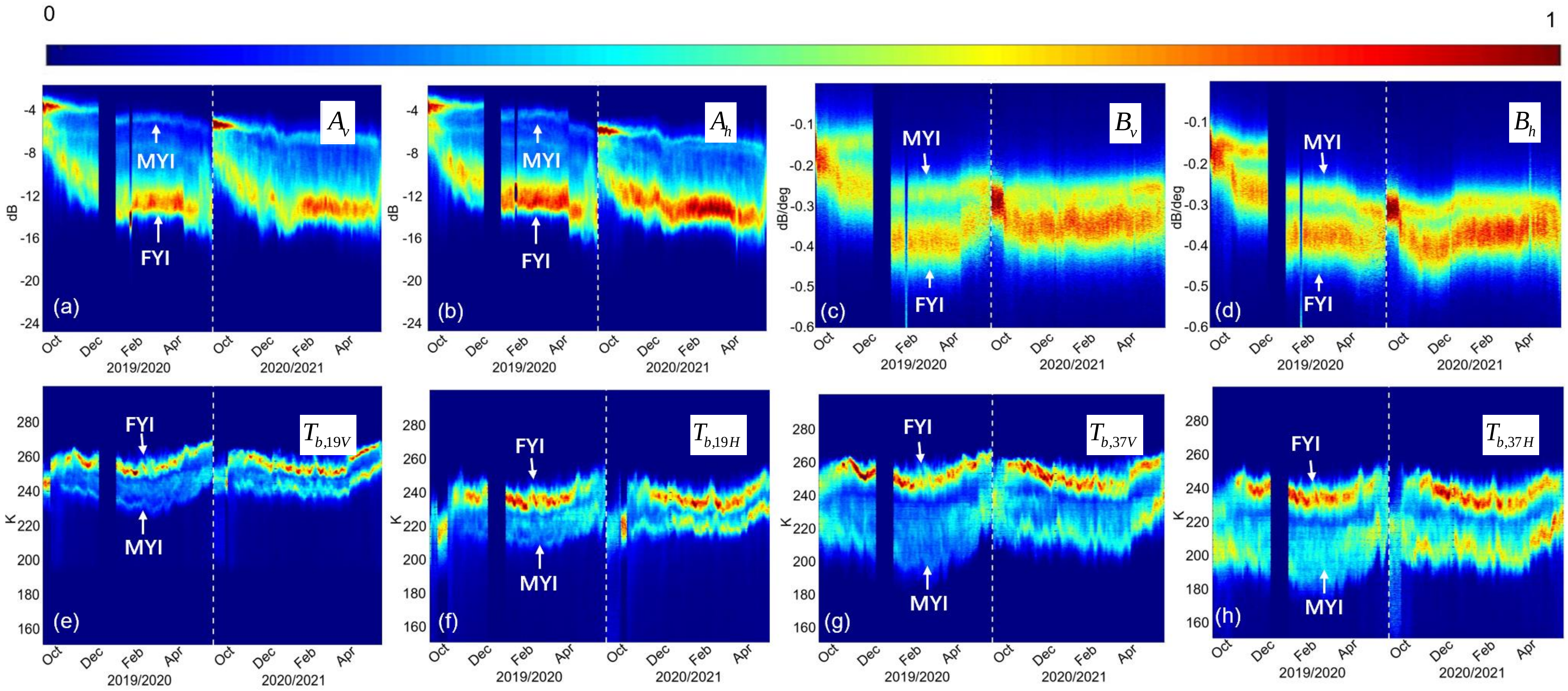
- **CFOSCAT data (October 1, 2019 - May 31, 2021)**
  $A$ (h-pol and v-pol) : $A$ is the backscatter coefficient ($\sigma_0$) value at 40° incidence.
  $B$ (h-pol and v-pol) : $B$ describes the dependence of $\sigma_0$ on incidence angle.




*The change of the CFOSCAT (a) v-pol and (b) h-pol backscatter coefficients with the incidence angle (from 28° to 51°) in the Arctic MYI region on January 1, 2021. The red line represents the fitted linear trend. The color indicates the number of samples.*

- **AMSR-2 brightness temperature ($T_b$) data (October 1, 2019 - May 31, 2021)**
  $T_b$ (h-pol and v-pol) of 18.7 GHz and 36.5 GHz (hereafter referred as 19 GHz and 37GHz)

# **Sea ice classification**-Dataset




*Histogram of the statistical distribution of observed values of different parameters over Arctic sea ice region in the winter of 2019/2020 and 2020/2021. The color represents the number of different observation values, which has been normalized to a range of 0-1.*

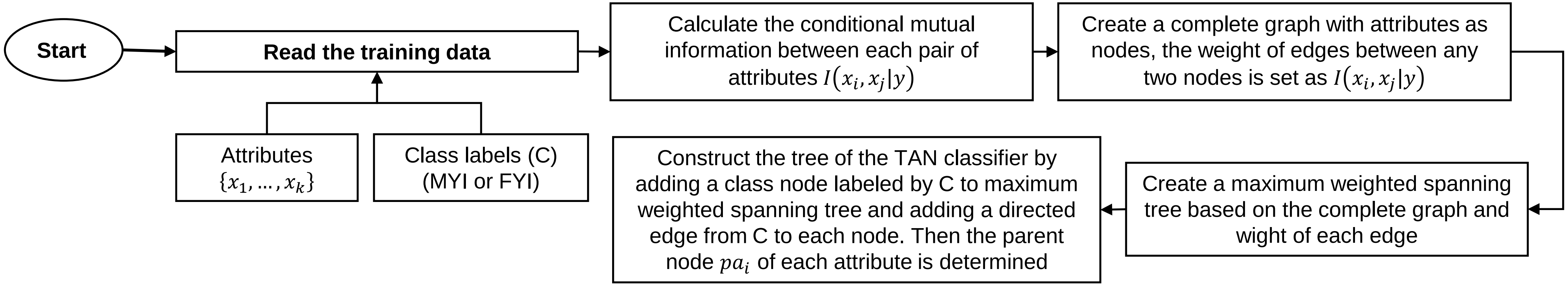
# Sea ice classification-Dataset

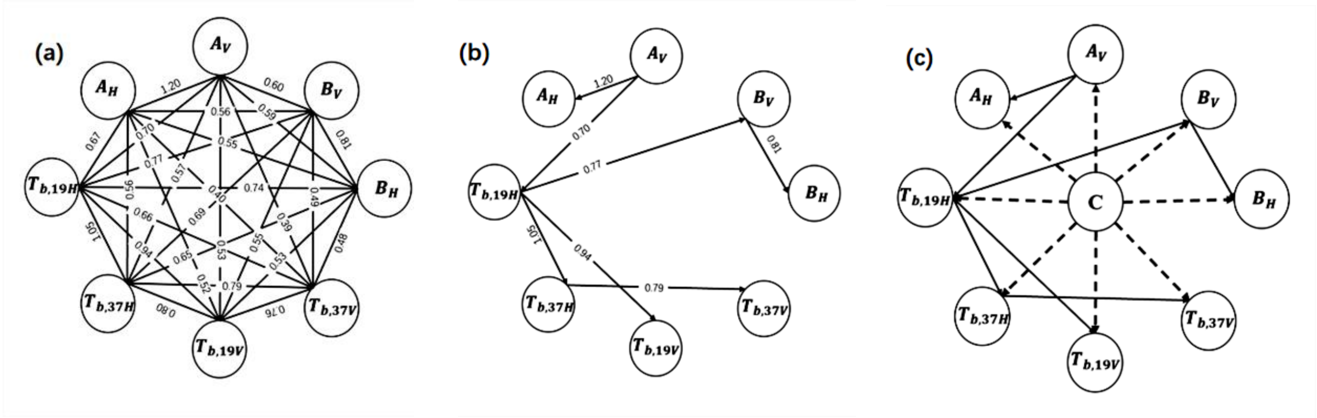
*The classification parameters used in different time periods*

| | $A_v$ | $A_h$ | $B_v$ | $B_h$ | $T_{b,19V}$ | $T_{b,19H}$ | $T_{b,37V}$ | $T_{b,37H}$ |
|---|---|---|---|---|---|---|---|---|
| October | ✓ | ✓ | / | / | / | / | ✓ | / |
| November - April | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| May | ✓ | ✓ | / | / | ✓ | / | ✓ | / |

# **Sea ice classification**- TAN algorithm

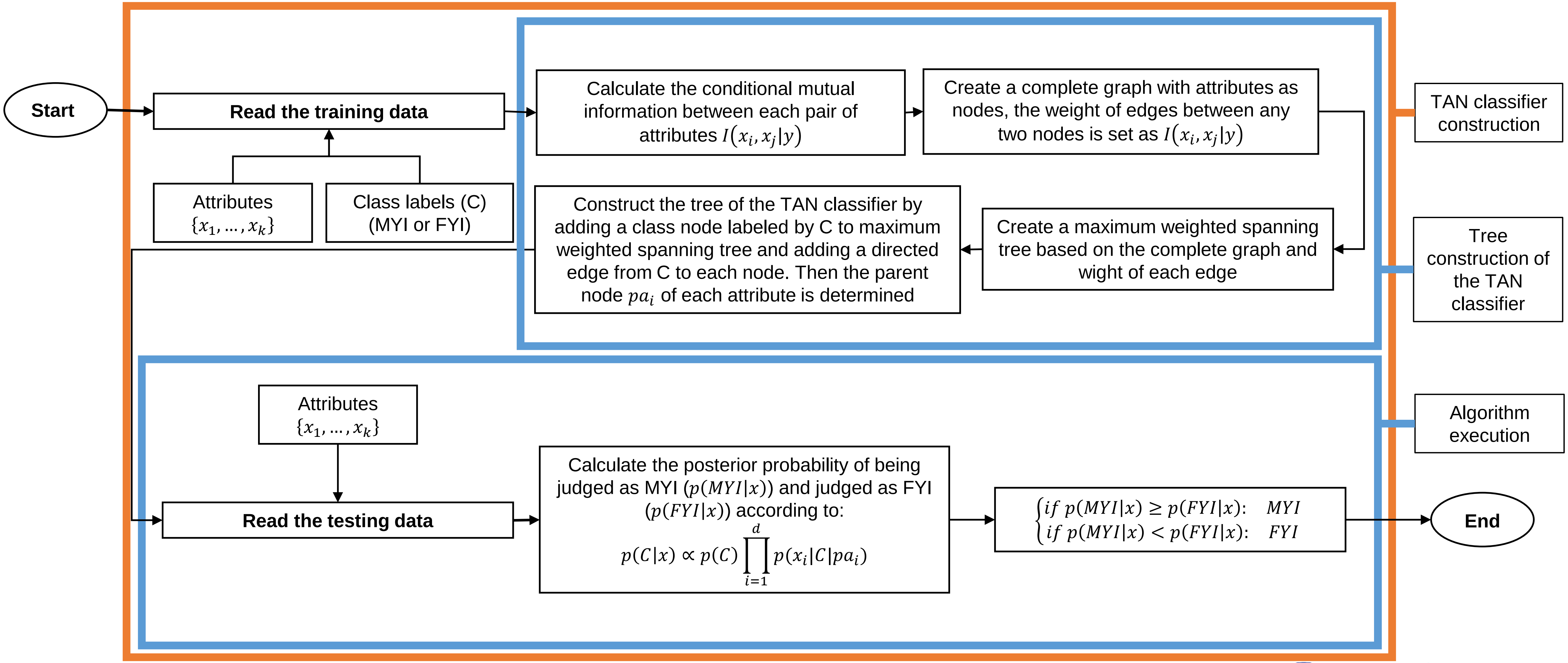
*Tree Augmented Naive Bayes*



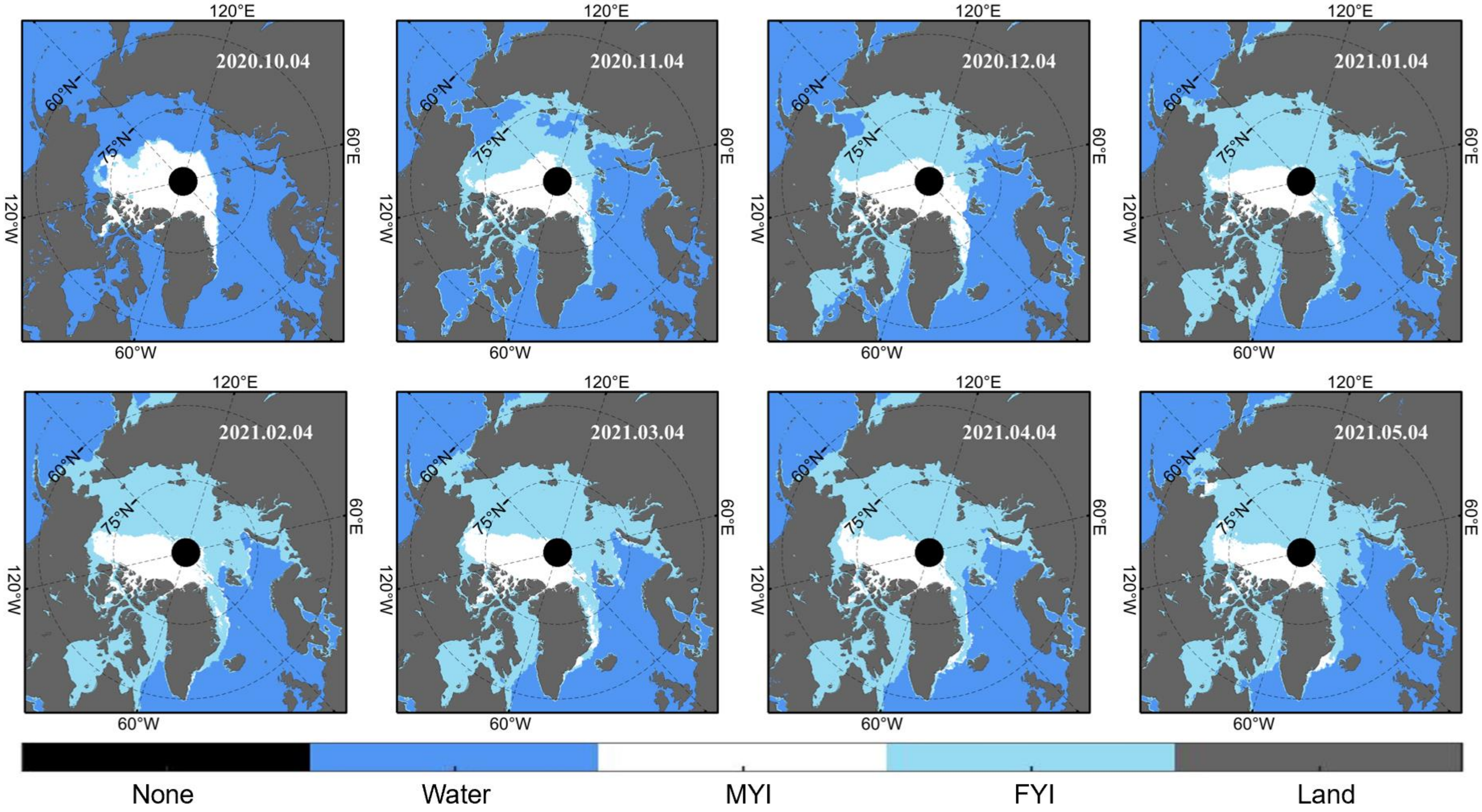




*Construct process of the tree of the TAN classifier (Take the period from January 2021 to April 2021 as an example). (a)-(c) represent the complete graph, the maximum weighted spanning tree, and the tree of the TAN classifier respectively.*

# Sea ice classification- TAN algorithm

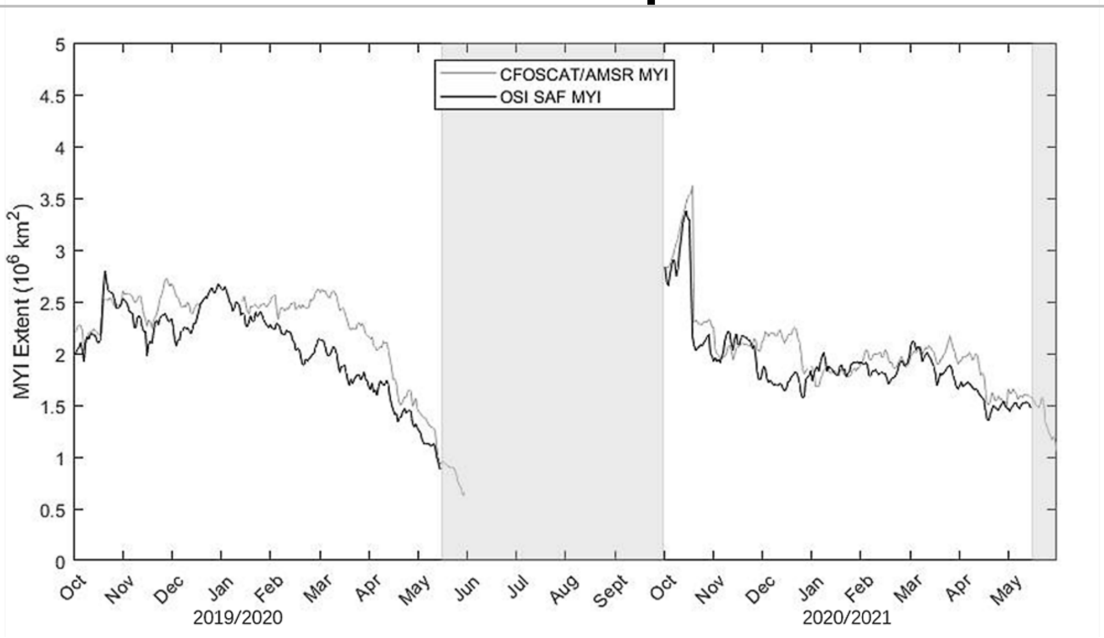


# **Sea ice classification**-Results (CFOSCAT/AMSR)




*Sea ice type maps selected from the winter of 2020/2021*

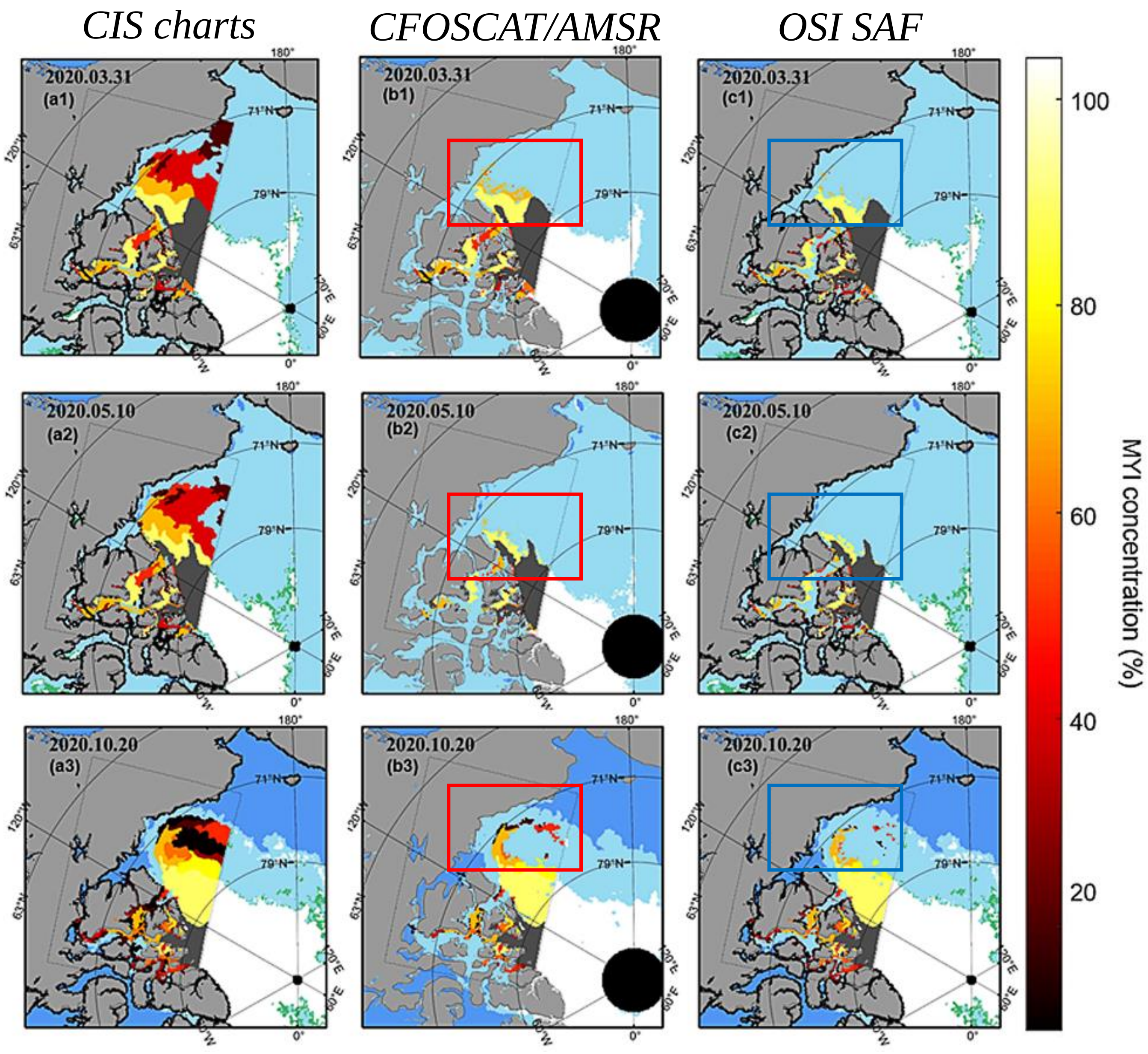
# **Sea ice classification**-Comparison and validation




*MYI extent variations of CFOSCAT/AMSR and OSI SAF (The gray part indicates the "Ambiguous" period in OSI SAF product).*

The MYI extent of CFOSCAT/AMSR and OSI SAF has roughly the same change trend. A relatively large MYI extent of CFOSCAT/AMSR can be found.

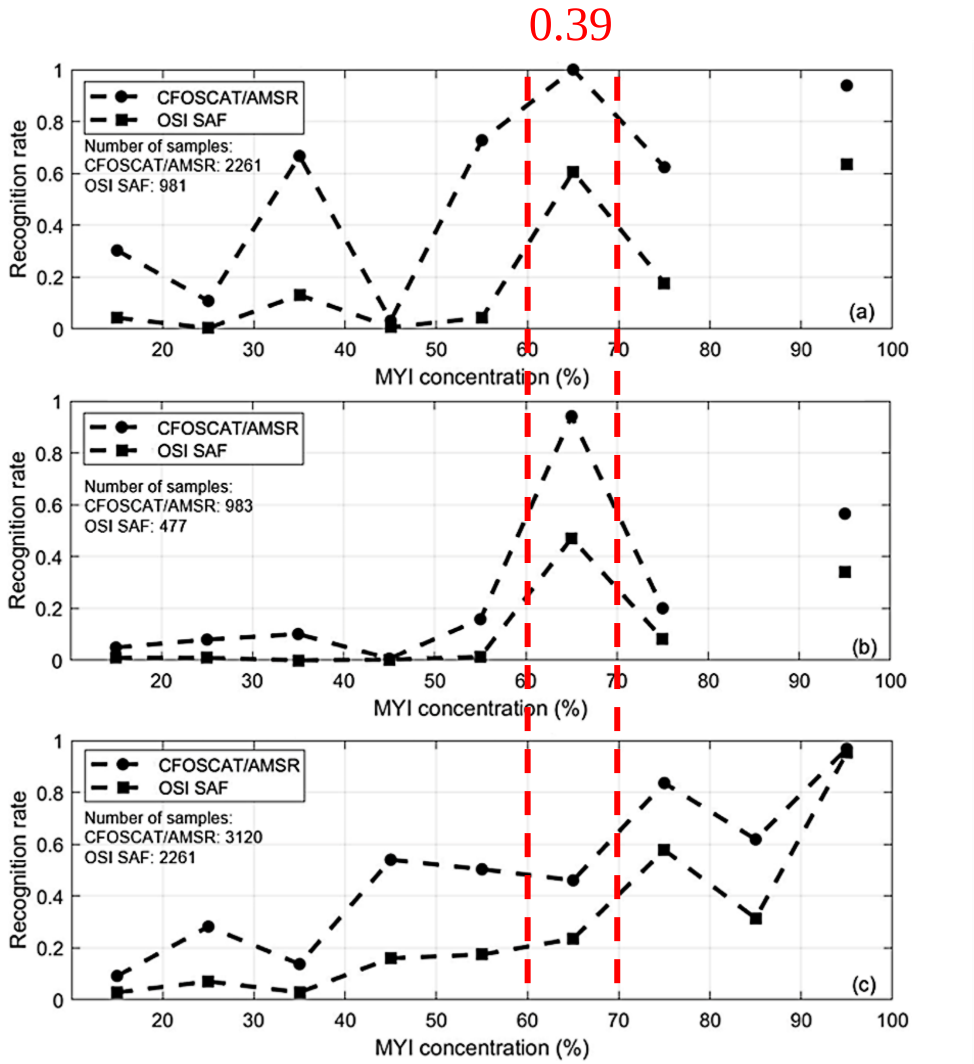
# **Sea ice classification**-Comparison and validation




*MYI concentration of (a1) - (a3) CIS charts, (b1) - (b3) CFOSCAT/AMSR, and (c1) - (c3) OSI SAF on Mar 31, 2020, May 10, 2020, and Oct 20, 2020 (The invalid concentration values are marked in dark gray).*

MYI concentration distributions of CIS charts, CFOSCAT/AMSR, and OSI SAF over the Western Arctic region (the region covered by CIS charts) on Mar 31, 2020, May 10, 2020, and Oct 20, 2020, are shown in the left figure. As can be seen from this figure, CFOSCAT/AMSR can identify more MYI pixels at lower MYI concentration compared with OSI SAF in the Western Arctic region.

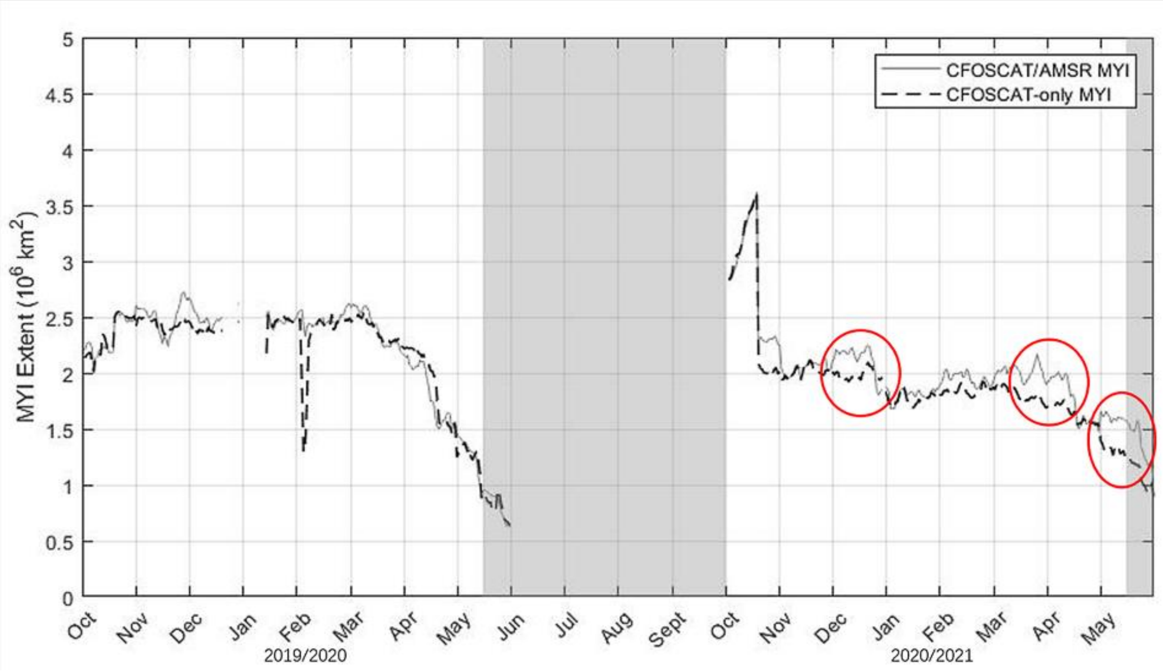
# **Sea ice classification**-Comparison and validation




*Recognition rates of CFOSCAT/AMSR results and OSI SAF products on (a) March 31, 2020, (b) May 10, 2020, and (c) October 20, 2020.*

We firstly divided MYI concentration into ten bins (with a width of 10%), and then calculated the recognition rates of CFOSCAT/AMSR and OSI SAF for MYI with different MYI concentrations. Recognition rates are defined as the ratio of the identified MYI pixels in a specified concentration bin to the total number of CIS charts MYI pixels corresponding to that concentration bin.

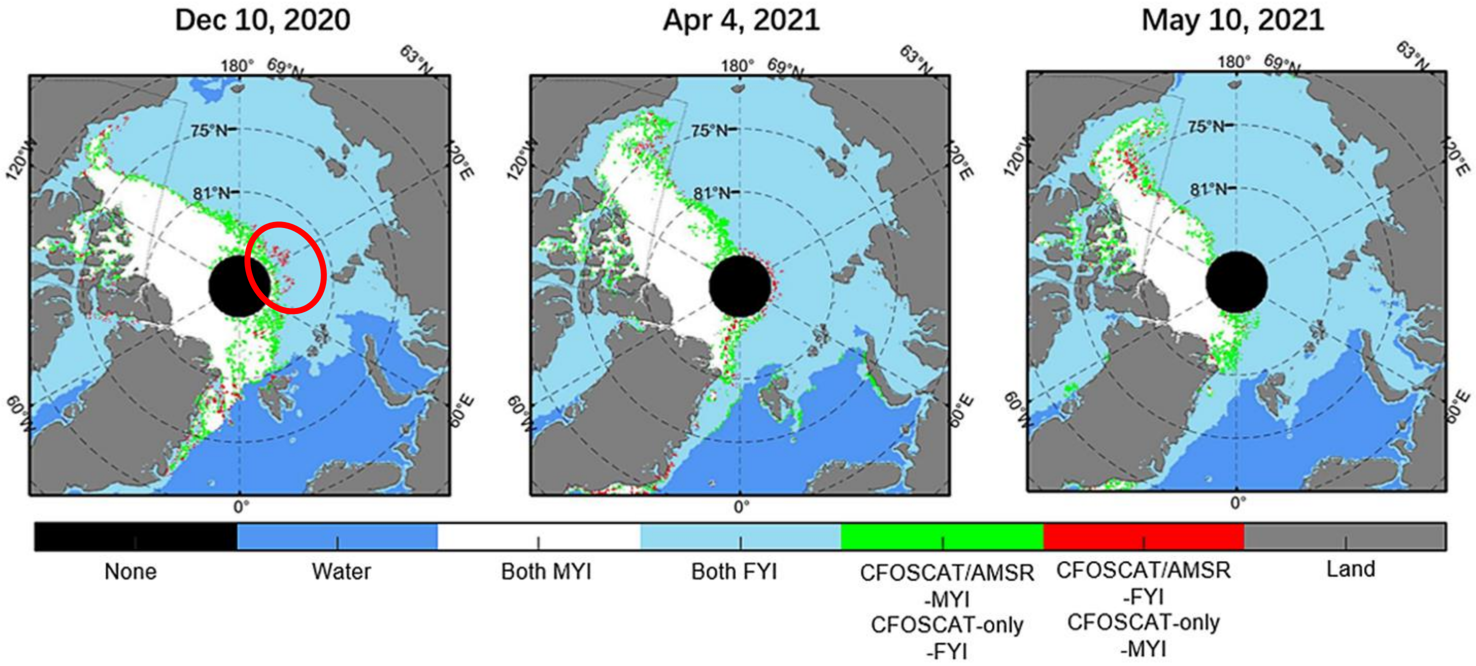
# **Sea ice classification**-Comparison and validation




*MYI extent variations of CFOSCAT/AMSR and CFOSCAT-only.*

The MYI extent of CFOSCAT-only (*the classification results using only CFOSCAT data*) maintains the same variation trend as that of CFOSCAT/AMSR especially in the winter of 2019/2020. In the winter of 2020/2021, the MYI extent variation of CFOSCAT-only shows a generally lower MYI extent than that of CFOSCAT/AMSR. The major differences between these two results mainly occur in December 2020, April 2021, and May 2021.

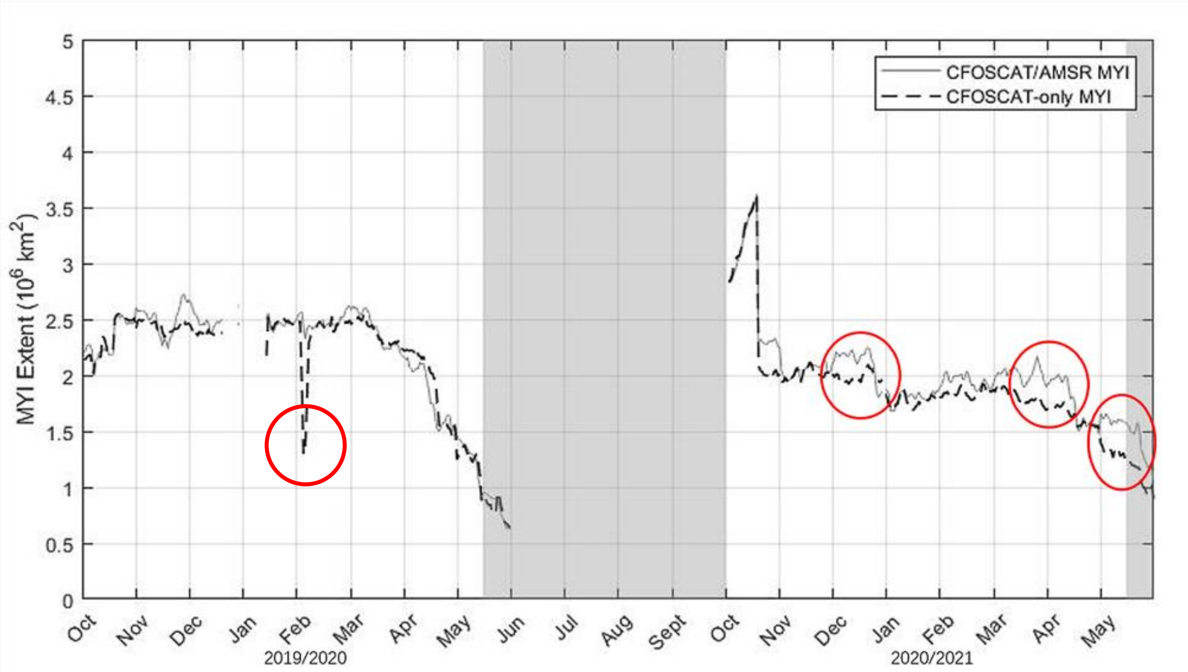
# **Sea ice classification**-Comparison and validation




*MYI distribution differences between the CFOSCAT-only results and CFOSCAT/AMSR results.*

- On December 10, 2020, the MYI pixels only detected by CFOSCAT-only located near 120°E longitude and 84°N latitude are likely to be misjudged because they are far away from the main part of the MYI.
- On April 4, 2021, the MYI which was only detected by CFOSCAT-only mainly distributes around the pole hole (black hole). These MYI pixels are also very likely to be misjudged.
- On May 10, 2021, MYI pixels only detected by CFOSCAT-only are very rare, with an extent of $1.53\times10^4$ $km^2$, accounting for only 1.0% of the CFOSCAT-only total MYI extent.

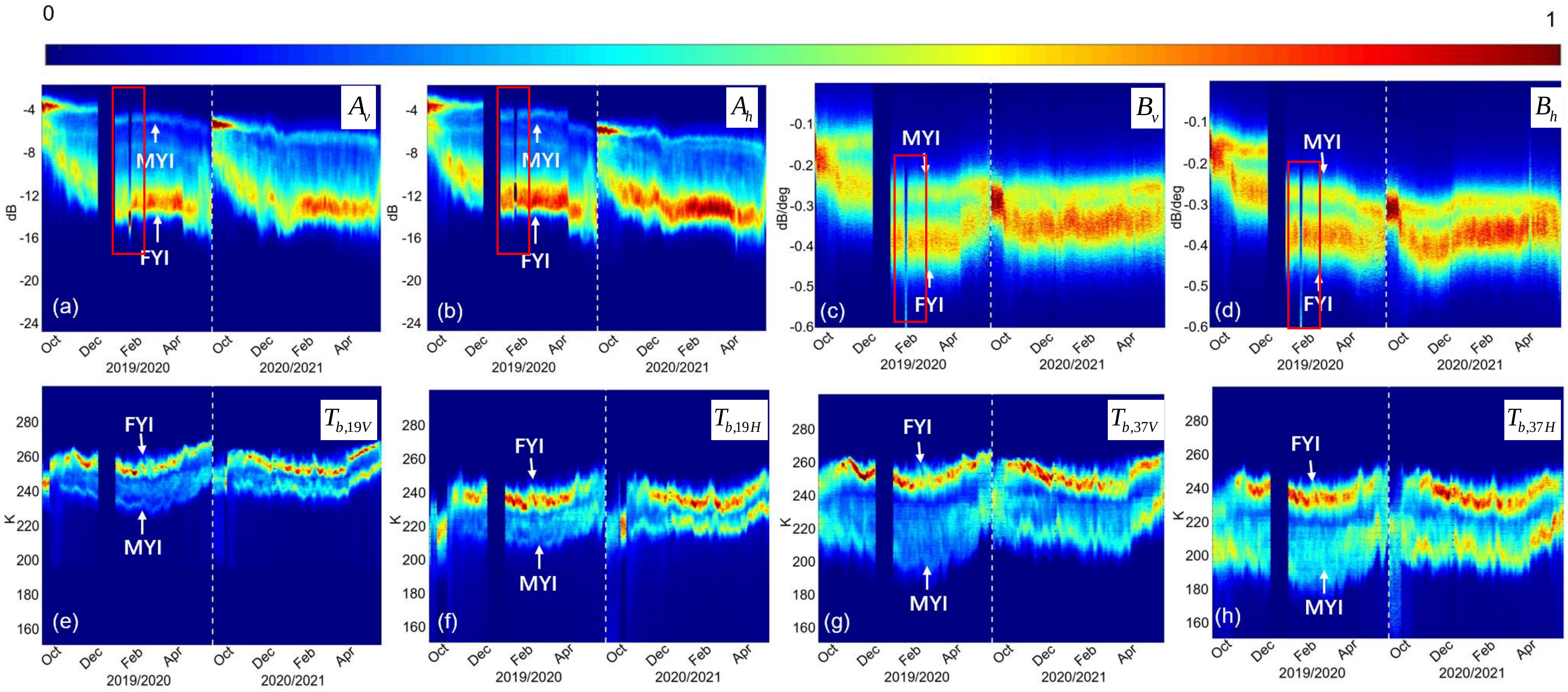
# **Sea ice classification**-Comparison and validation




*MYI extent variations of CFOSCAT/AMSR and CFOSCAT-only.*

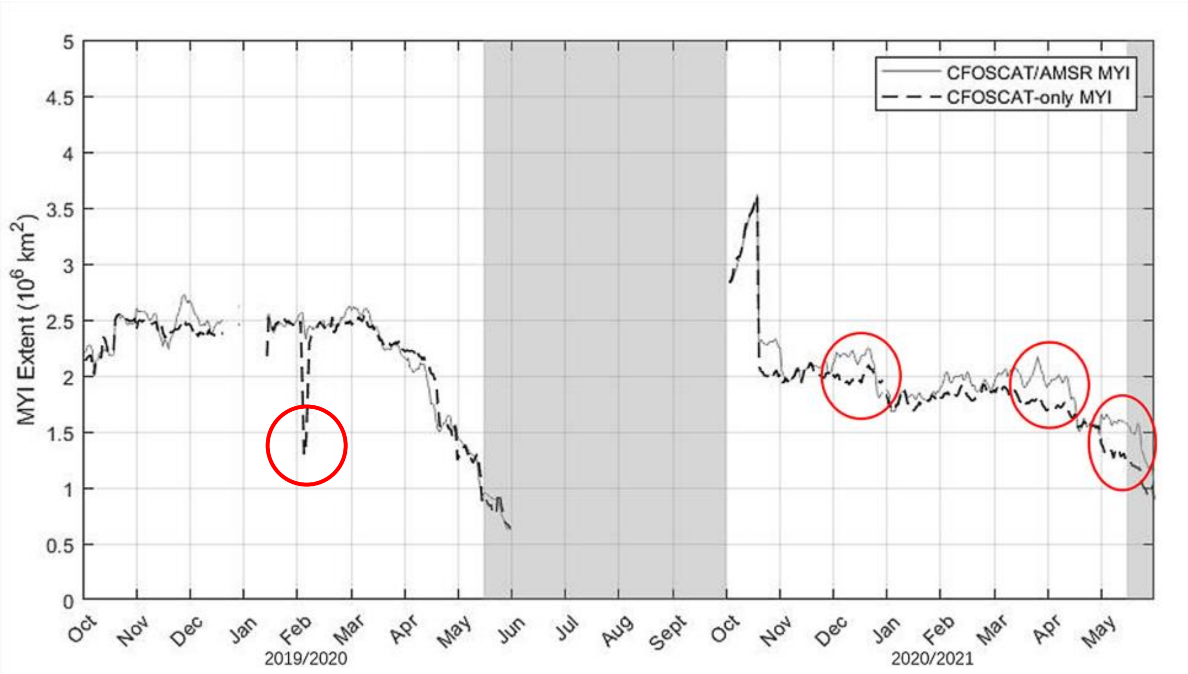
An anomaly of CFOSCAT-only MYI extent in February 2020 is observed. The addition of AMSR-2 data neutralizes the appearance of this outlier.

# Sea ice classification-Comparison and validation




*Histogram of the statistical distribution of observed values of different parameters over Arctic MYI and FYI main area in the winter of 2019/2020 and 2020/2021. The color represents the number of different observation values, which has been normalized to a range of 0-1*

# **Sea ice classification**-Comparison and validation



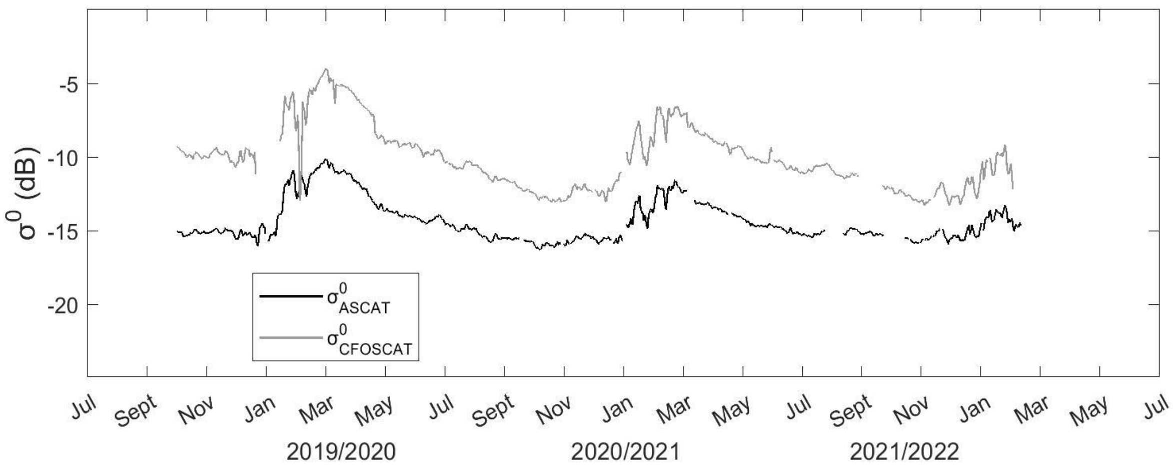

*MYI extent variations of CFOSCAT/AMSR and CFOSCAT-only.*

An anomaly of CFOSCAT-only MYI extent in February 2020 is observed. The addition of AMSR-2 data neutralizes the appearance of this outlier.

# **Snowmelt onset retrieval**-Dataset & Methodology

**Main data** ▸ backscatter coefficients: Ku-band: CFOSCAT / C-band: ASCAT

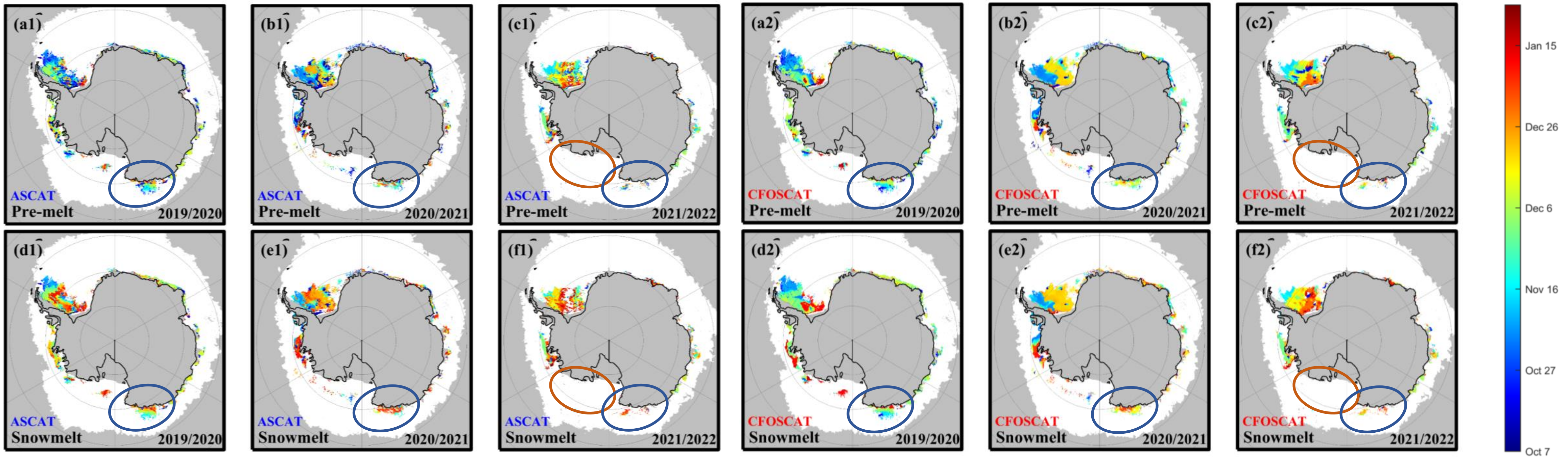
**-Pre-melt onset (PMO):** the initial warming and destructive metamorphism of the snowpack
**-Snowmelt onset (SMO):** thaw-freeze cycle onset and superimposed ice begins to form




Pre-melt onset: subtle increase in backscatter (2dB)

Snowmelt onset: large increase in backscatter (3dB)

# **Pre-melt and snowmelt onset retrieval**-Results (pan-Antarctic MYI region)



*Pre-melt and snowmelt onsets of the pan-Antarctic MYI region*

- Weddell Sea: snowmelt onset is getting earlier from south to north. As for pre-melt onset, a more pronounced latitudinal variation in CFOSCAT results than ASCAT can be observed.
- In other regions: The Western Ross Sea region shows a trend of earlier snowmelt onset as latitude moved from south to north. In 2021/2022, the perennial sea ice in the Western Amundsen Sea and the Eastern Ross Sea has almost completely disappeared.

*Mean pre-melt and snowmelt onset results for different regions and time periods*

**ASCAT**

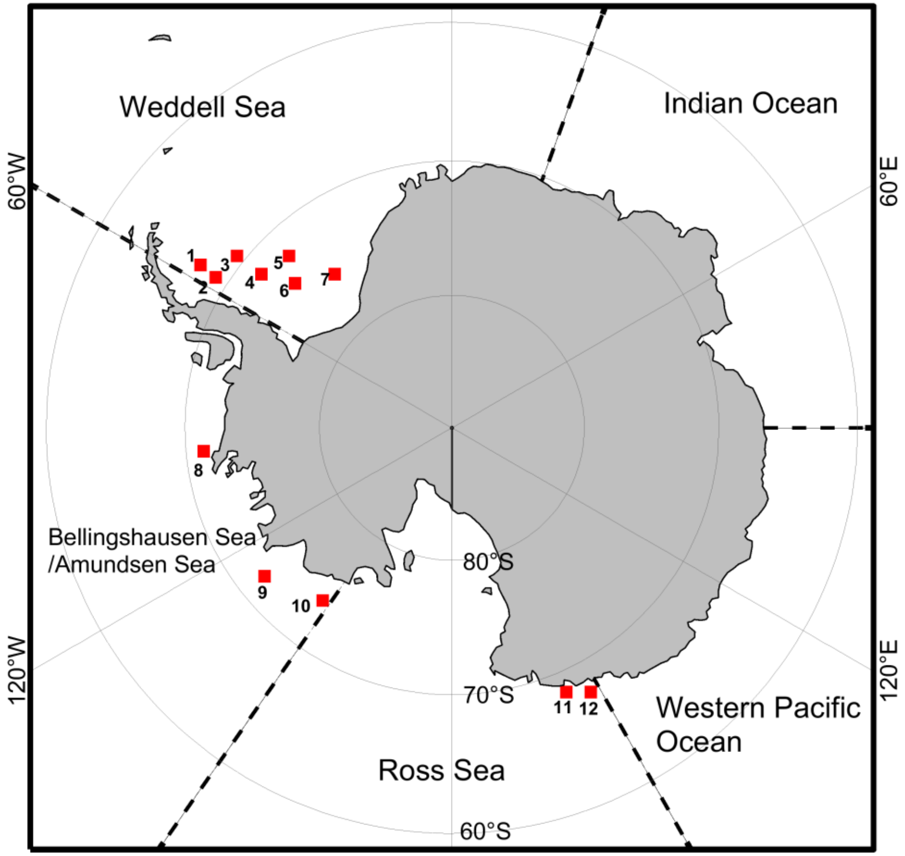
| **Regions** | Pre-melt onset | | | | Snowmelt onset | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | 2019/2020 | 2020/2021 | 2021/2022 | All time periods | 2019/2020 | 2020/2021 | 2021/2022 | All time periods |
| **Northwestern Weddell Sea** | Nov 15 | Nov 18 | Dec 2 | Nov 22 | Dec 5 | Dec 5 | Dec 20 | Dec 10 |
| **Southeastern Weddell Sea** | Nov 18 | Nov 21 | Dec 10 | Nov 27 | Dec 19 | Dec 10 | Dec 25 | Dec18 |
| **Bellingshau-sen Sea & Amundsen Sea** | Nov 24 | Nov 23 | Dec 8 | Nov 28 | Dec 12 | Dec 16 | Dec 20 | Dec 16 |
| **Ross Sea** | Nov 26 | Nov 18 | Dec 2 | Nov 29 | Dec 15 | Dec 19 | Dec 28 | Dec 21 |
| **All regions** | Nov 21 | Nov 23 | Dec 5 | **Nov 26** | Dec 13 | Dec 13 | Dec 23 | **Dec 16** |

**CFOSCAT**

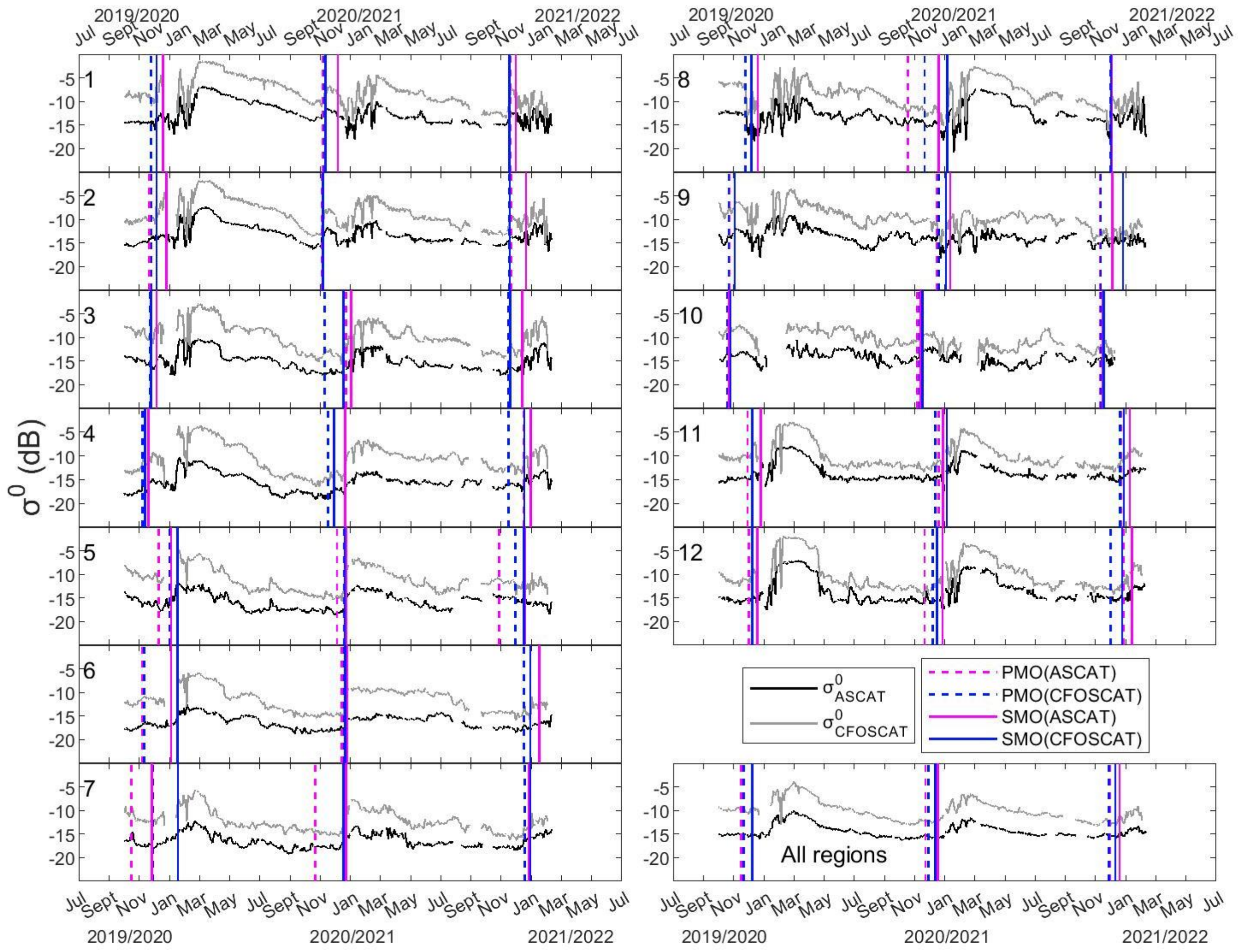
| **Regions** | Pre-melt onset | | | | Snowmelt onset | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | 2019/2020 | 2020/2021 | 2021/2022 | All time periods | 2019/2020 | 2020/2021 | 2021/2022 | All time periods |
| **Northwestern Weddell Sea** | Nov 13 | Nov 19 | Nov 25 | Nov 20 | Nov 24 | Nov 30 | Dec 7 | Dec 1 |
| **Southeastern Weddell Sea** | Dec 7 | Dec 4 | Dec 8 | Dec 7 | Dec 31 | Dec 15 | Dec 24 | Dec 23 |
| **Bellingshau-sen Sea & Amundsen Sea** | Dec 1 | Nov 27 | Nov 30 | Nov 30 | Dec 22 | Dec 9 | Dec 13 | Dec 15 |
| **Ross Sea** | Nov 29 | Dec 4 | Dec 5 | Dec 3 | Dec 10 | Dec 19 | Dec 19 | Dec 17 |
| **All regions** | Nov 28 | Nov 30 | Dec 2 | **Nov 30** | Dec 14 | Dec 12 | Dec 16 | **Dec 14** |

- Spatial variability: Ross Sea has the relative late pre-melt and snowmelt onsets compared with other regions. The pre-melt and snowmelt onset dates in Southeastern Weddell Sea are much later than those in the Northwestern Weddell Sea region
- Interannual variability: Pre-melt and snowmelt onsets tend to become later year over year across all regions
- Difference between the Ku- and C-band scatterometers: Ku-band sensor detects earlier mean snowmelt onsets than the C-band sensor. The C-band sensor detects earlier mean pre-melt onsets than the Ku-band sensor

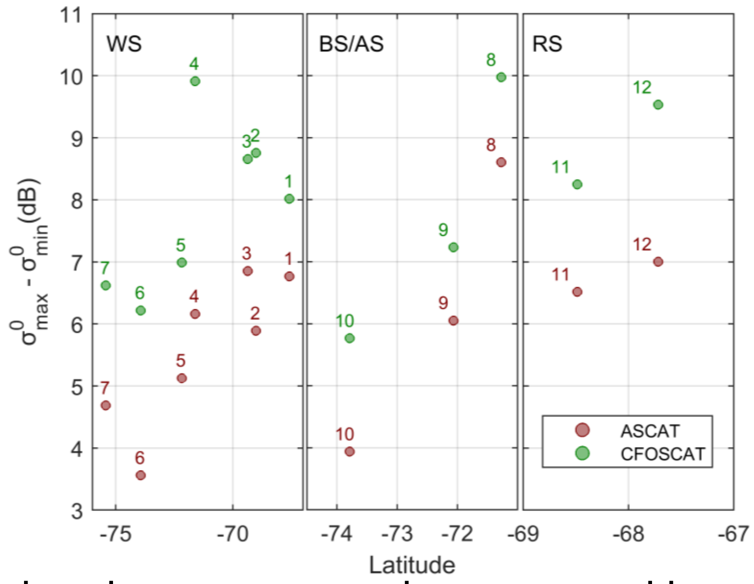
# Pre-melt and snowmelt onset retrieval-Results (12 MYI study sites)



# **Pre-melt and snowmelt onset retrieval**-Results (12 perennial sea ice study sites)




*Variations of the differences between seasonal maxima and minima (seasonal amplitude) with latitudes*




- Ku-band scatterometer is more sensitive to the Antarctic snowmelt than C-band scatterometer

$$ASCAT\ (\sigma^0_{max} - \sigma^0_{min}) = 5.9\text{dB}$$

$$CFOSCAT\ (\sigma^0_{max} - \sigma^0_{min}) = 8.0\text{dB}$$

- The higher the latitude, the smaller the amplitude value

# Conclusion

- Based on data of CFOSCAT and AMSR-2, we classified the sea ice type for the winter from 2019 to 2021 in Arctic by using the TAN classifier
- Validation results showed that CFOSCAT/AMSR and OSI SAF maintained basically the same trend of MYI extent change on the whole. Besides, CFOSCAT/AMSR had a better ability to detect MYI at a lower MYI concentration than OSI SAF in the Western Arctic region
- We also compared the CFOSCAT/AMSR sea ice classification results with the CFOSCAT-only results. The comparison showed that the use of AMSR-2 data can correct errors caused by CFOSCAT parameter outliers
- The results suggests that the TAN sea ice type classification method can provide reliable ice type classification results. However, further validation of our results using other sea ice products to have a long-term quantitative validation is needed

- The pre-melt and snowmelt onset from 2019 to 2022 were retrieved based on the backscatter of C-band ASCAT and Ku-band CFOSCAT
- CFOSCAT detects earlier snowmelt onsets than ASCAT
- The apparent latitudinal variations of backscatter amplitude and snowmelt onsets are observed
- Combining data from multiband scatterometers can help to observe the variation of vertical snow properties on MYI in Antarctic


Thanks!