Analysis of the Antarctic Marginal Ice Zone Based on Unsupervised Classification of Model Data

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Australian Research Council

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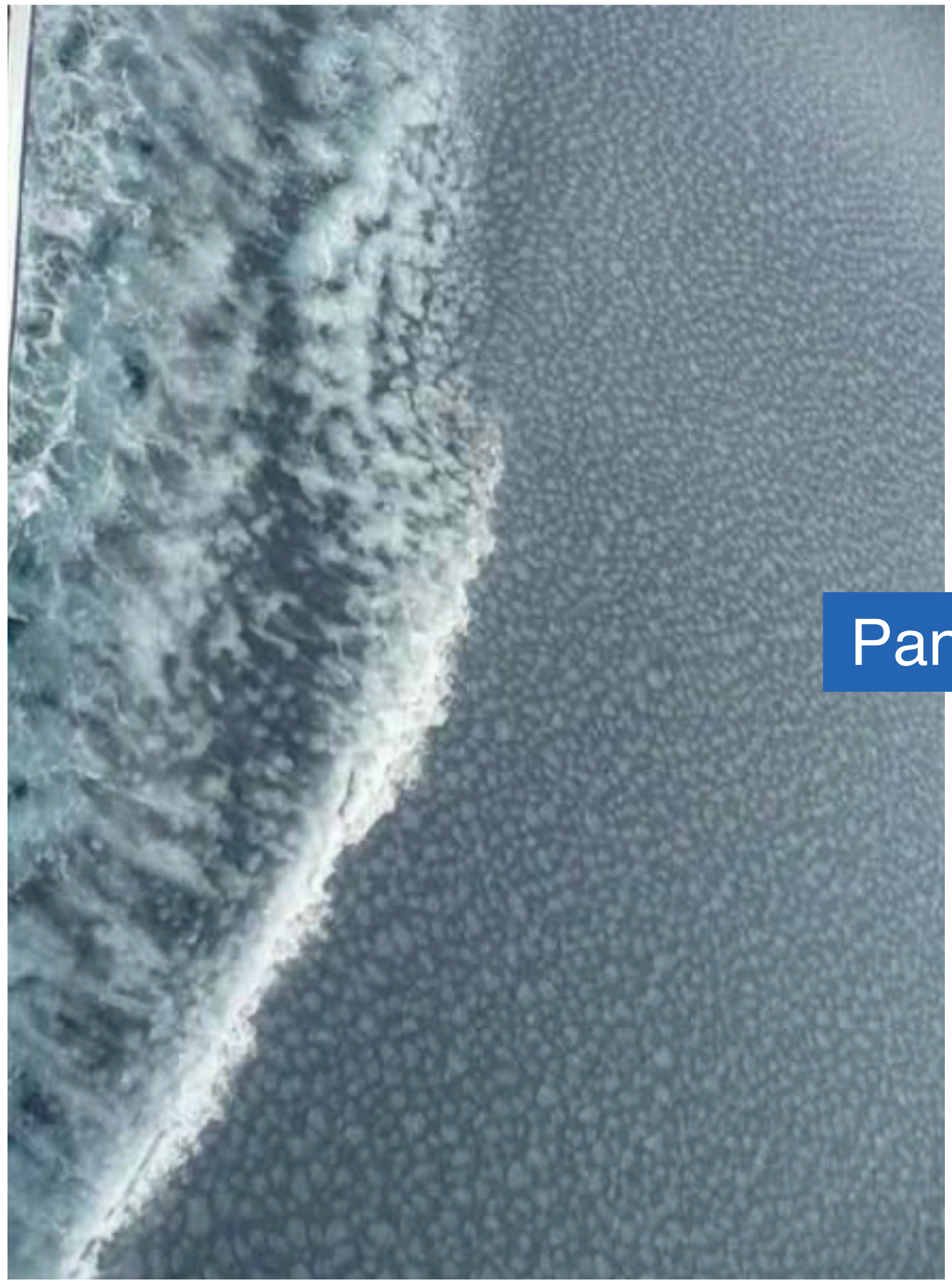
The Antarctic marginal ice zone (MIZ)

Credit: Alberto Alberello

New ice formation in the MIZ

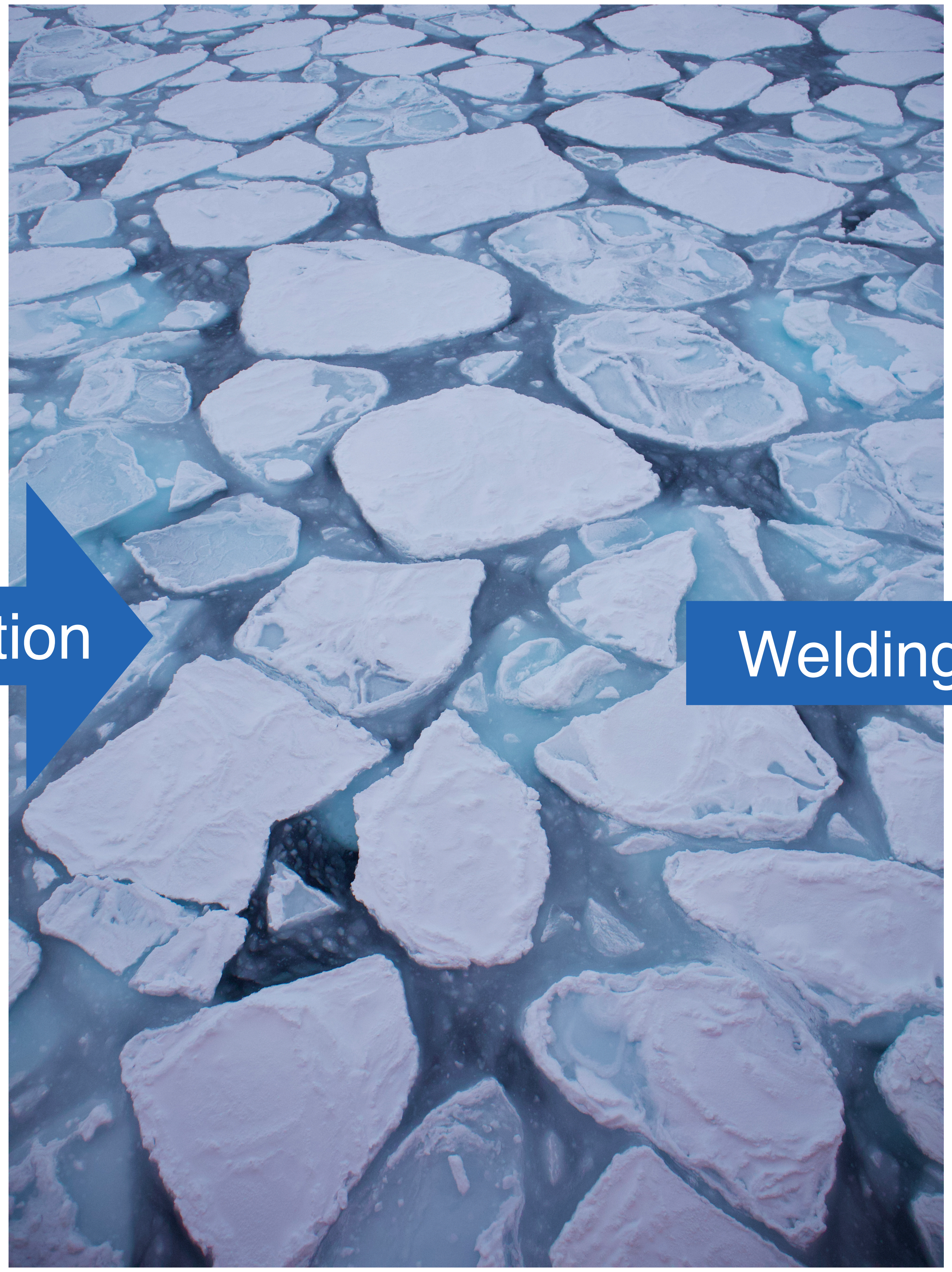
Frazil and small pancakes



Credit: Elizabeth Weir

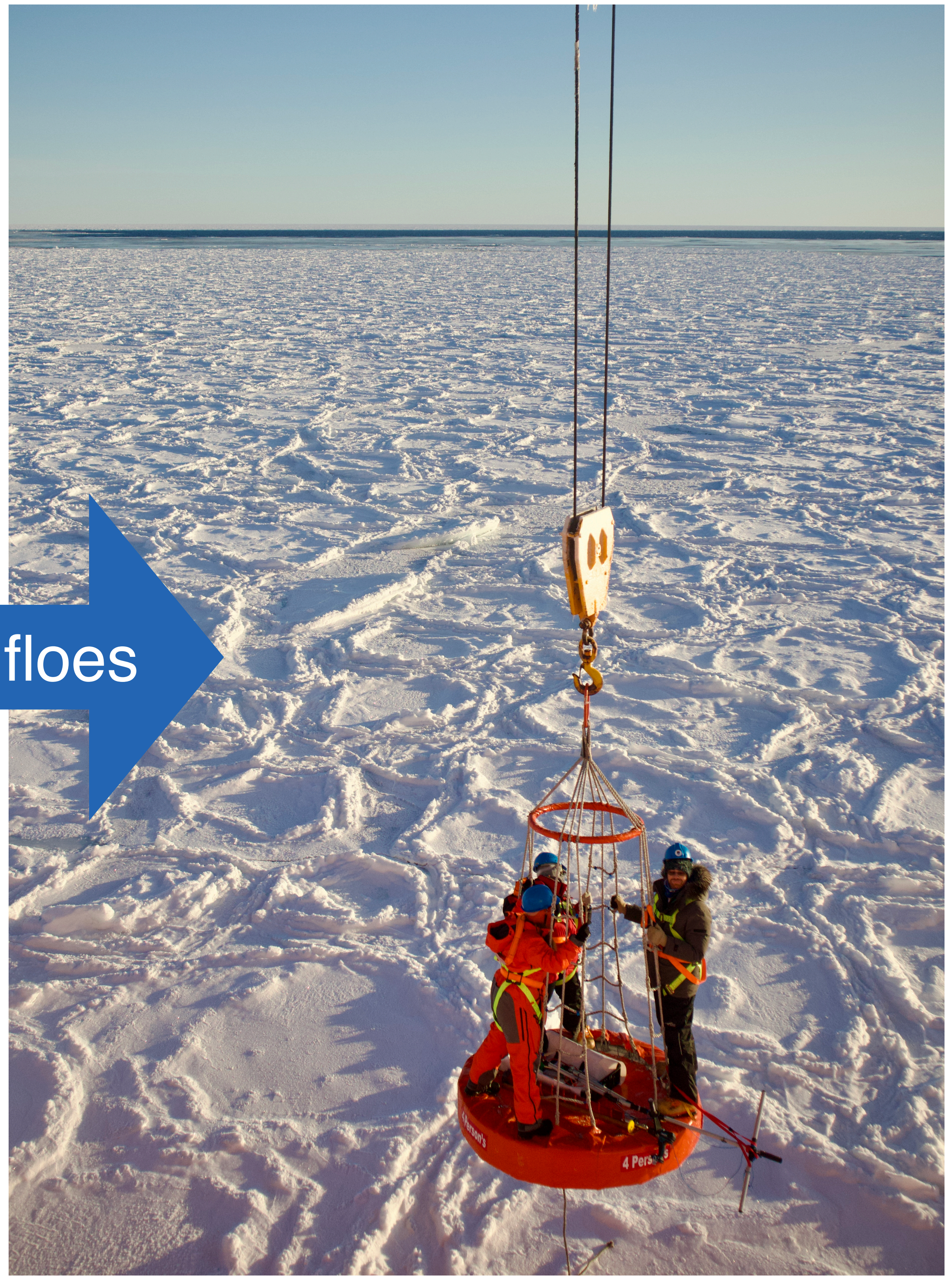
Pancake formation

Pancake floes



Welding between floes

Consolidation of pancakes



SCALE 2022 (credit: Kurt Martin/@kurt_artin)

Wave-ice interactions

Image: Dumas-Lefebvre and Dumont, *Cryosphere*, 2023

Wave-ice interactions

Image: Dumas-Lefebvre and Dumont, *Cryosphere*, 2023

Marginal ice zone processes

- During winter the Antarctic MIZ has been observed to be highly mobile and experience large waves, despite sea ice concentration being near 100%[1]
- Wave breakup can occur 100s of km from the ice edge [2]
- Small floes (e.g., broken floes, pancakes) are more prone to melting [3]
- MIZ studies are hindered by the lack of a pragmatic definition [4]


LETTER

doi:10.1038/nature13262

Storm-induced sea-ice breakup and the implications for ice extent

A. L. Kohout, M. J. M. Williams, S. M. Dean & M. H. Meylan

JGR Oceans

RESEARCH ARTICLE

10.1029/2019JC015418

Drift of Pancake Ice Floes in the Winter Antarcti[c] Marginal Ice Zone During Polar Cyclones

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 97, NO. C11, PAGES 17,729–17,738, NOVEMBER 15, 1992

Sea Ice Melting and Floe Geometry in a Simple Ice-Ocean Model

MICHAEL STEELE

PHILOSOPHICAL TRANSACTIONS A

royalsocietypublishing.org/journal/rsta

A prognostic synopsis of contemporary marginal ice zone research

Vernon A. Squire

Department of Mathematics and Statistics, University of Otago, PO Box 56, Dunedin 9016, New Zealand

Discussion

Cite this article: Squire VA. 2022 A prognostic synopsis of contemporary marginal ice zone research. Phil. Trans. R. Soc. A 380: 20220094. https://doi.org/10.1098/rsta.2022.0094

Received: 25 April 2022
Accepted: 4 June 2022

[1] Alberello, JGR: Oceans, 2020
[2] Kohout et al., Nature, 2014
[3] Steele, JGR, 1992
[4] Squire, Phil. Trans., 2022

How can we determine the width of the MIZ?

- 🧊Sea ice concentrations between 15—80% has been used historically as it is relatively easy to measure, however, MIZ dynamics also occur in near 100% concentrations [5]

- 🌊 Wave heights have been used recently [6, 7], although waves also have a pre-conditioning effect on the ice (i.e., pancake ice formation)

- Floe size (radius) could tell us if floes have been affected by waves by either process

[5] Alberello et al., Nature Comms, 2023
[6] Horvat et al., GRL, 2020
[7] Brouwer et al., Cryosphere, 2022

How can we determine the width of the MIZ?

- What is a

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🌊 Wav ... ave a pre-c

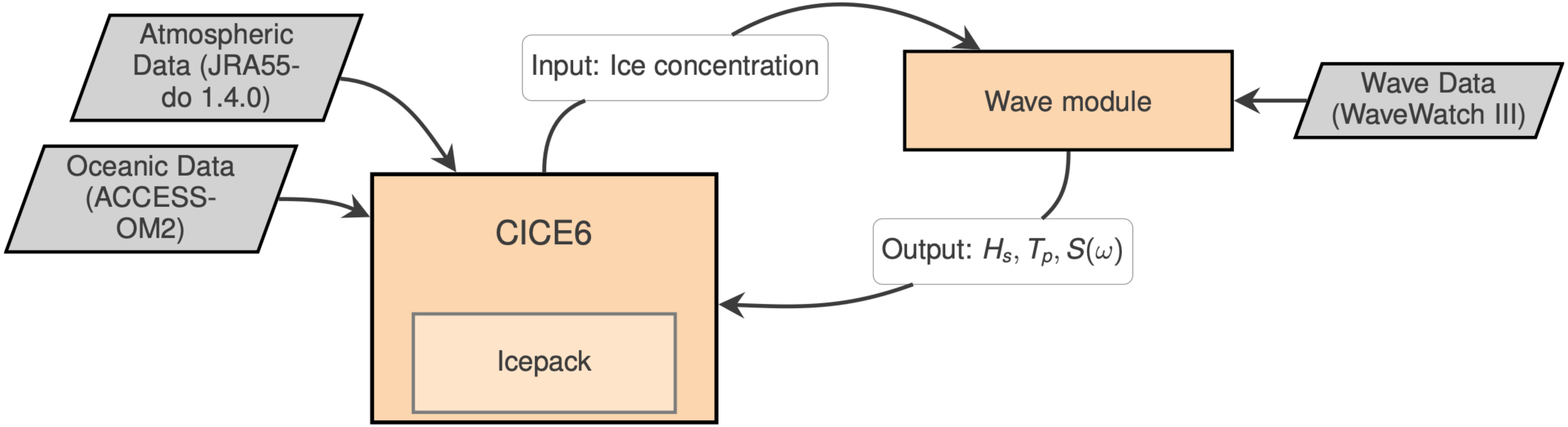
Floe ... es by either p

So, what is the best discriminator for separating the Antarctic marginal ice zone from the inner pack?

[5] Alberello et al., Nature Comms, 2023
[6] Horvat et al., GRL, 2020
[7] Brouwer et al., Cryosphere, 2022

Step 1: Collecting sea ice data

- We analyse standalone CICE6 (a global numerical sea ice model) outputs at 1° horizontal resolution
- CICE6 includes a module that models floe size (FSTD) [8]

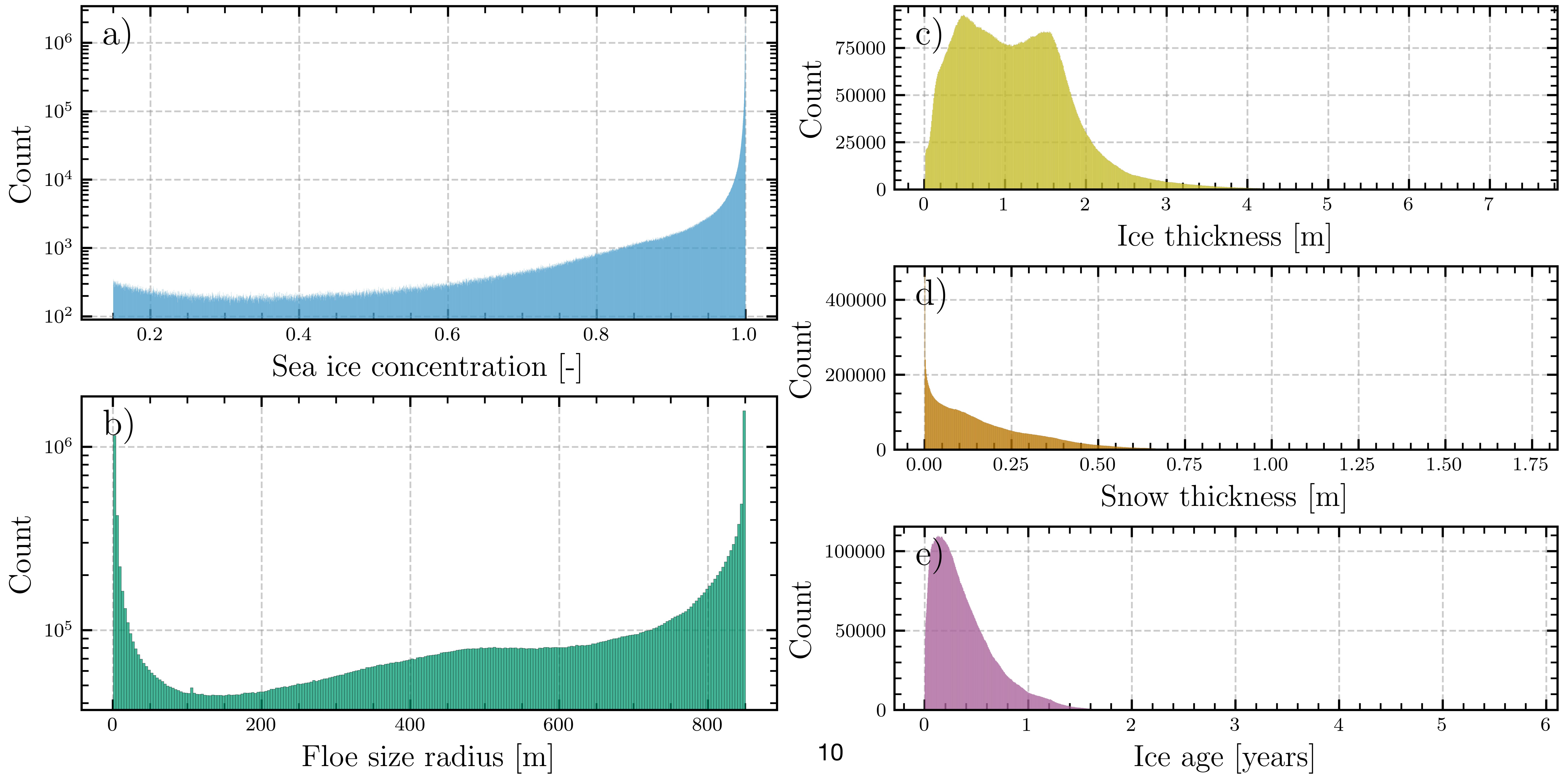


Model configuration of standalone CICE6 with a waves-in-ice module (CICE6-WIM).

[8] Roach et al., JAMES, 2019

Data overview

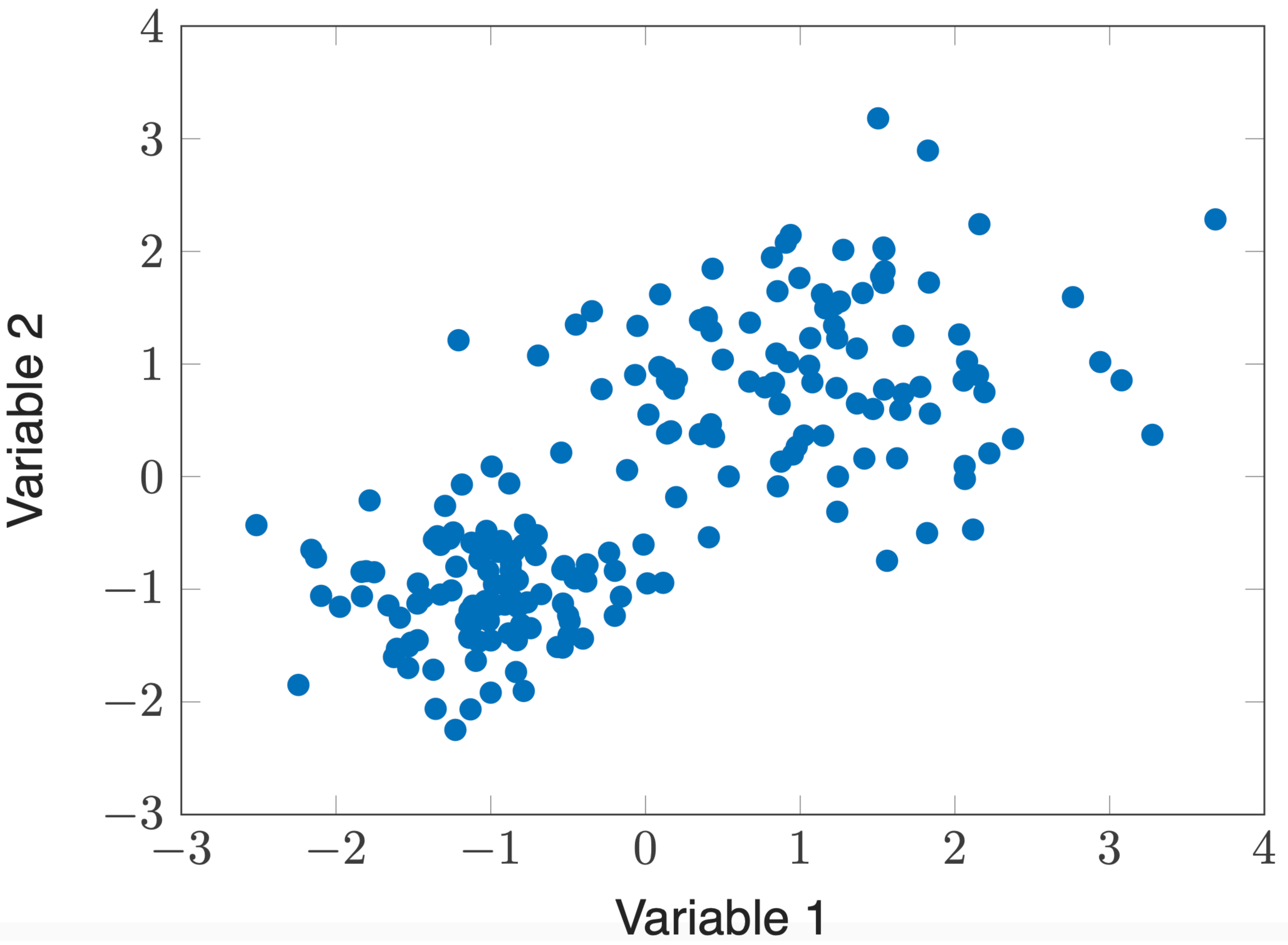
Daily model outputs of 5 sea ice properties over 2010—2019



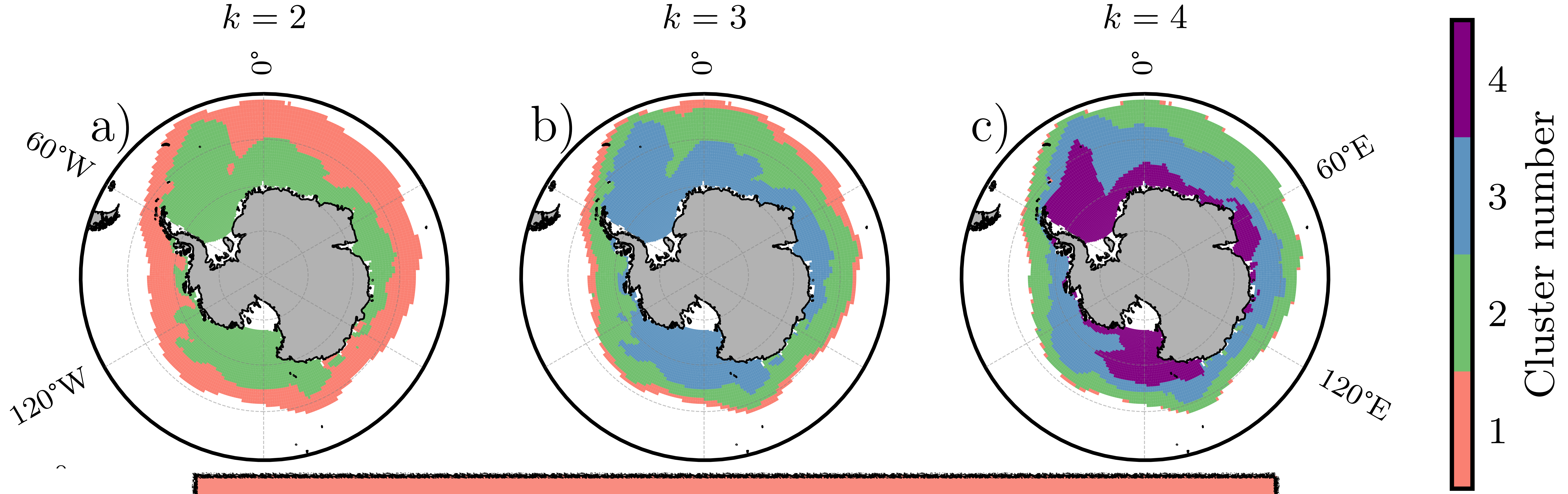
Step 2: Classifying the sea ice data

- *k*-means is an algorithm which clusters similar datapoints into distinct classes

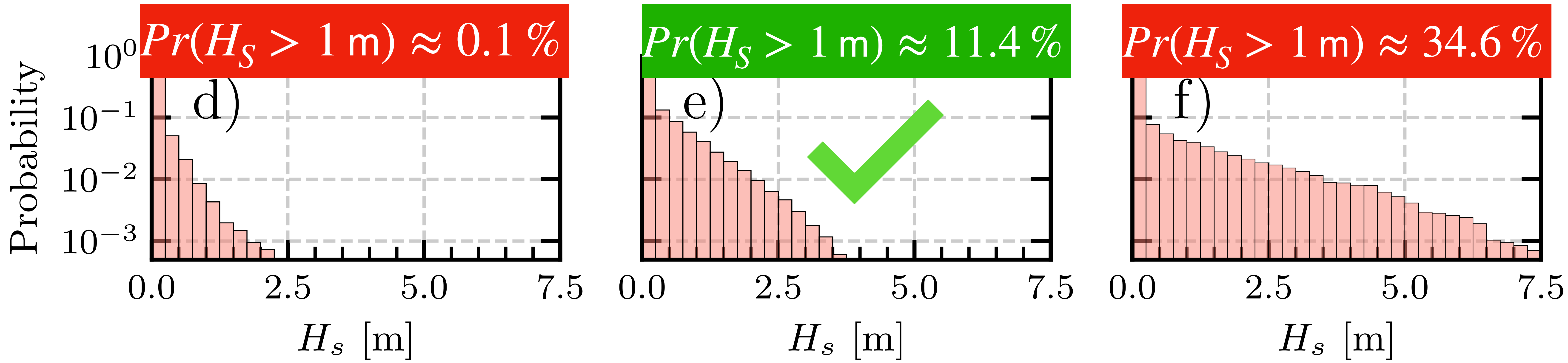
- We cluster on 5 sea ice variables we think are important to differentiate ice regions (SIC, thickness, age, floe size, snow thickness)



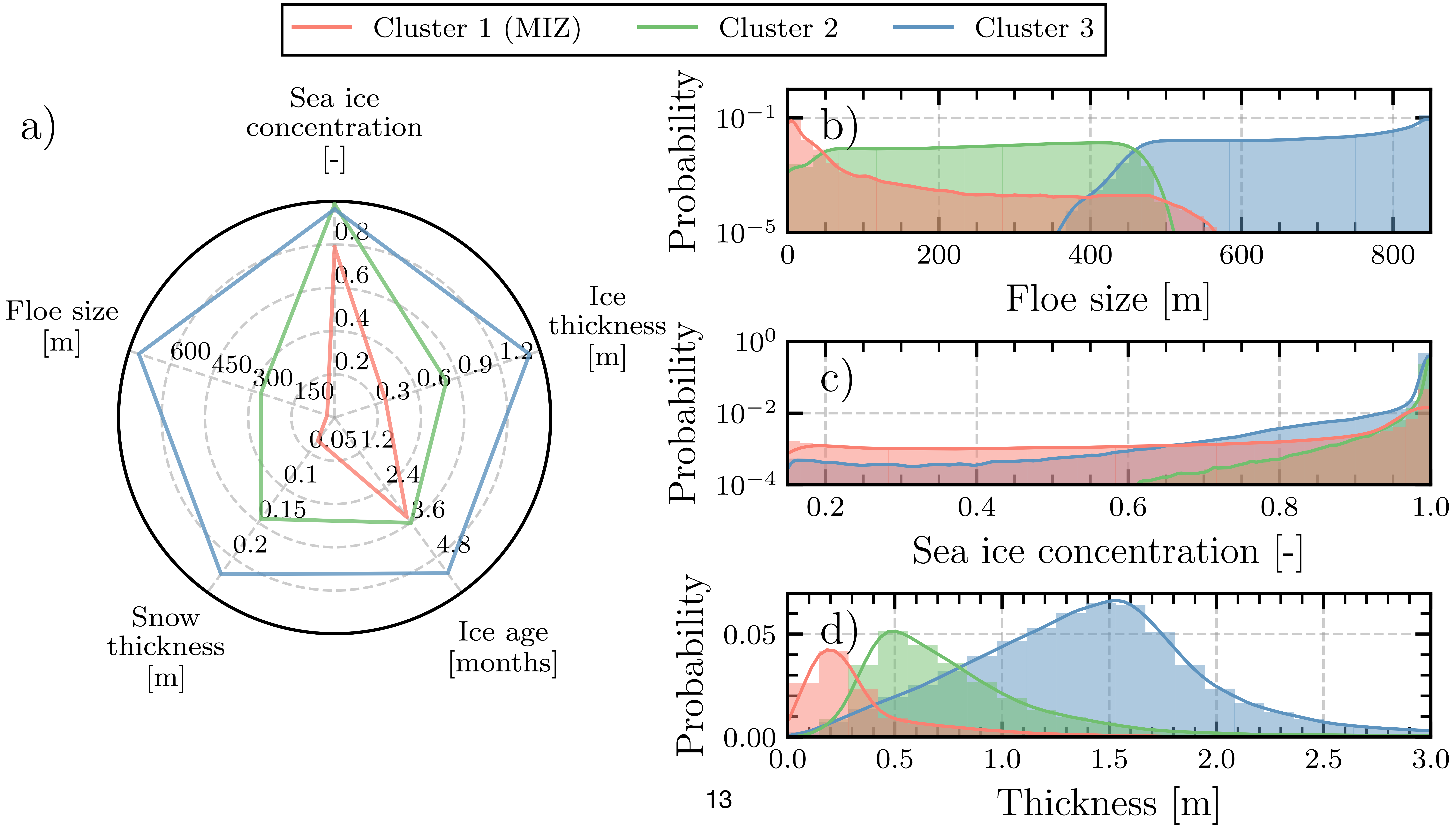
How many clusters (k) do we need?



Significant wave heights at the interior boundary of the MIZ

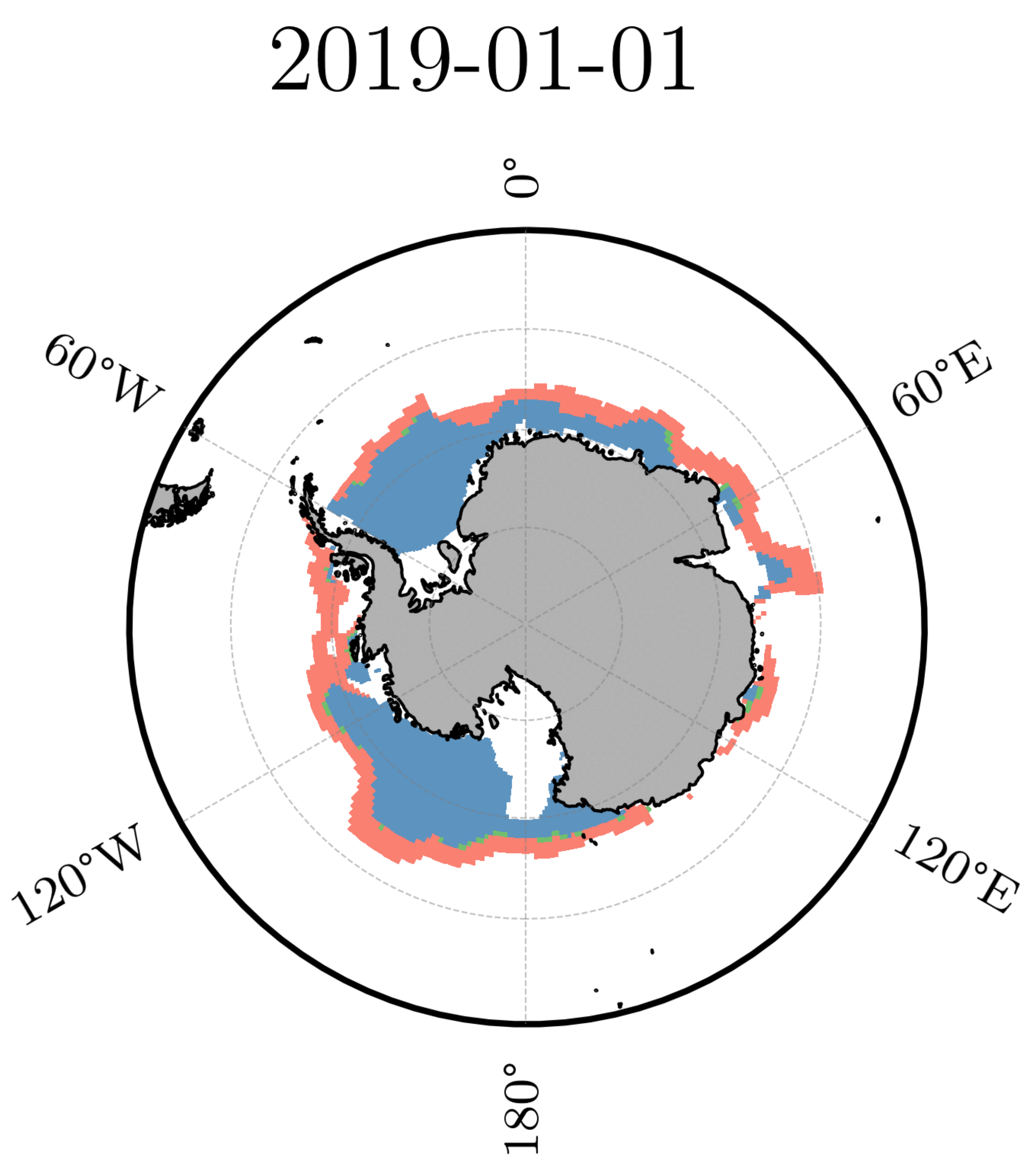


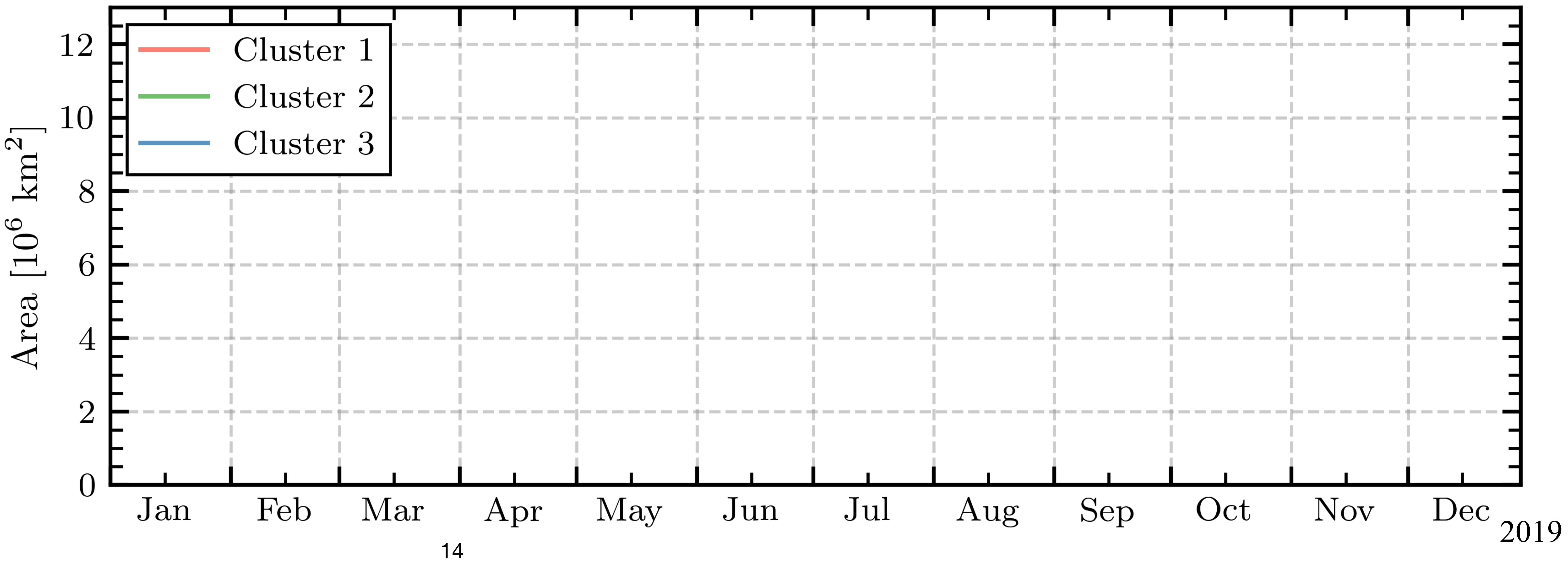
Mean characteristic of the sea ice clusters



Evolution of the sea ice clusters

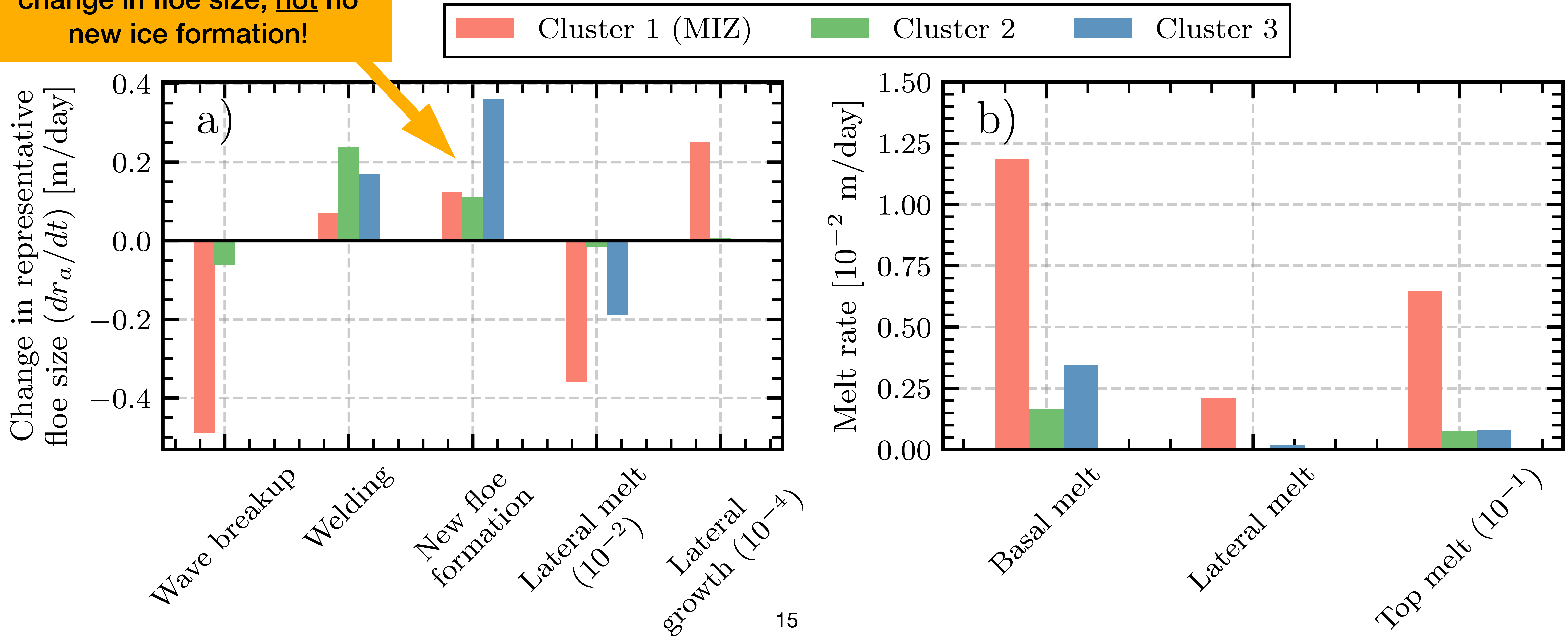
- MIZ small, young, thin, unconsolidated floes
- Cluster 2 larger, young, thin consolidated floes
- Cluster 3 largest, oldest, and thickest consolidated floes





Comparing averaged floe size processes and melt rates

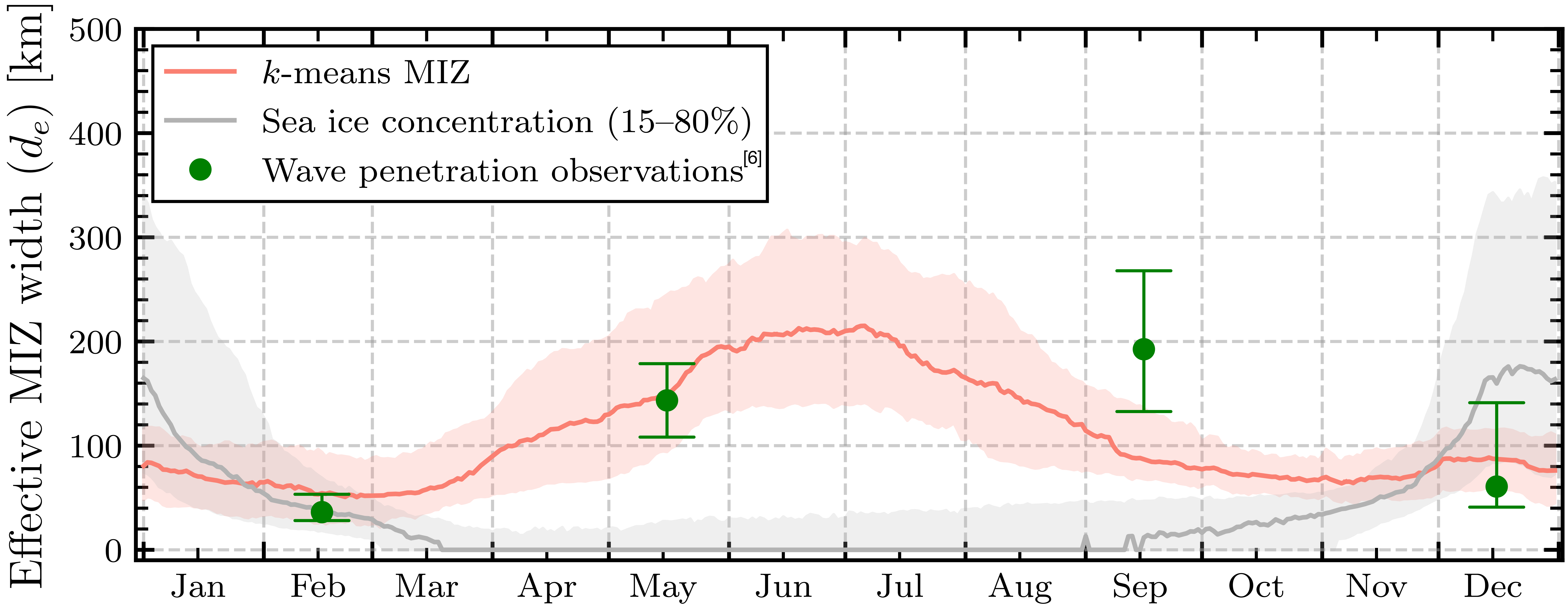
Small values mean little change in floe size, not no new ice formation!



Comparison of MIZ methods

Given $a_i(x)$ is the ice concentration at position x, the effective MIZ width is:

$$d_e = \int_0^d a_i(x)\mathrm{d}x\,.$$



[6] Brouwer et al., *Cryosphere*, 2022

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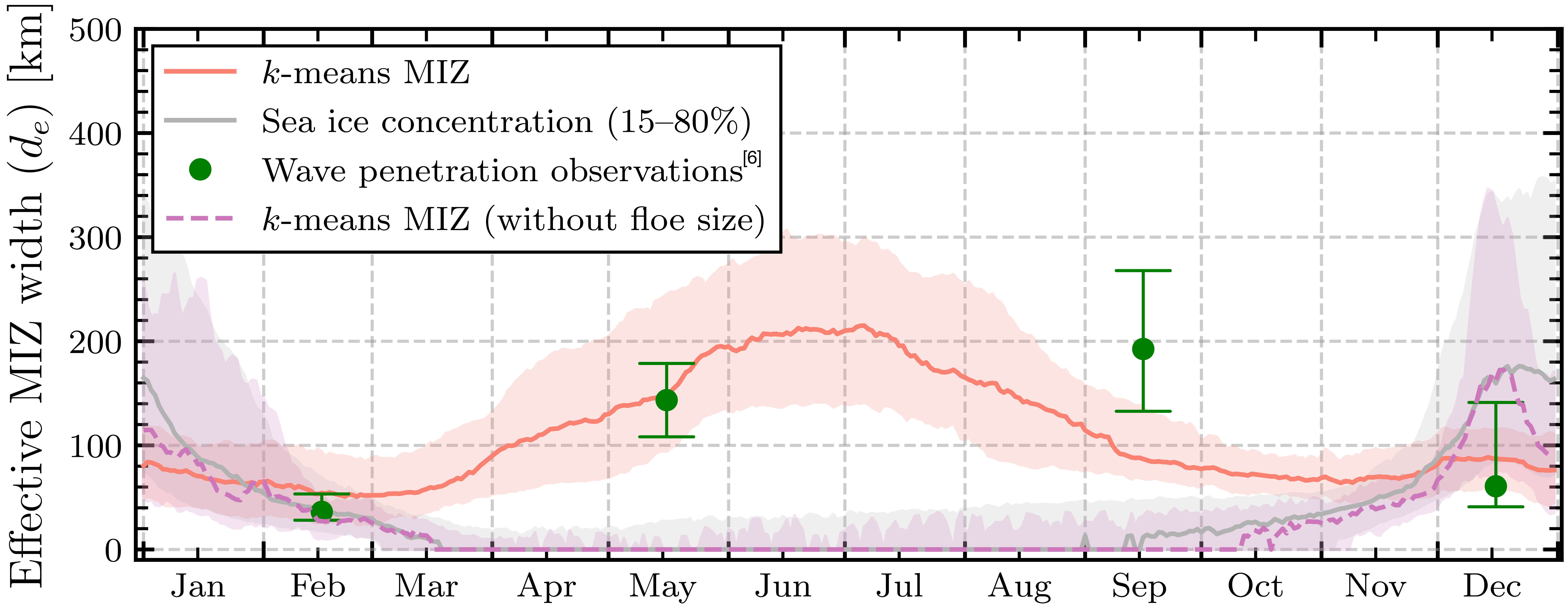
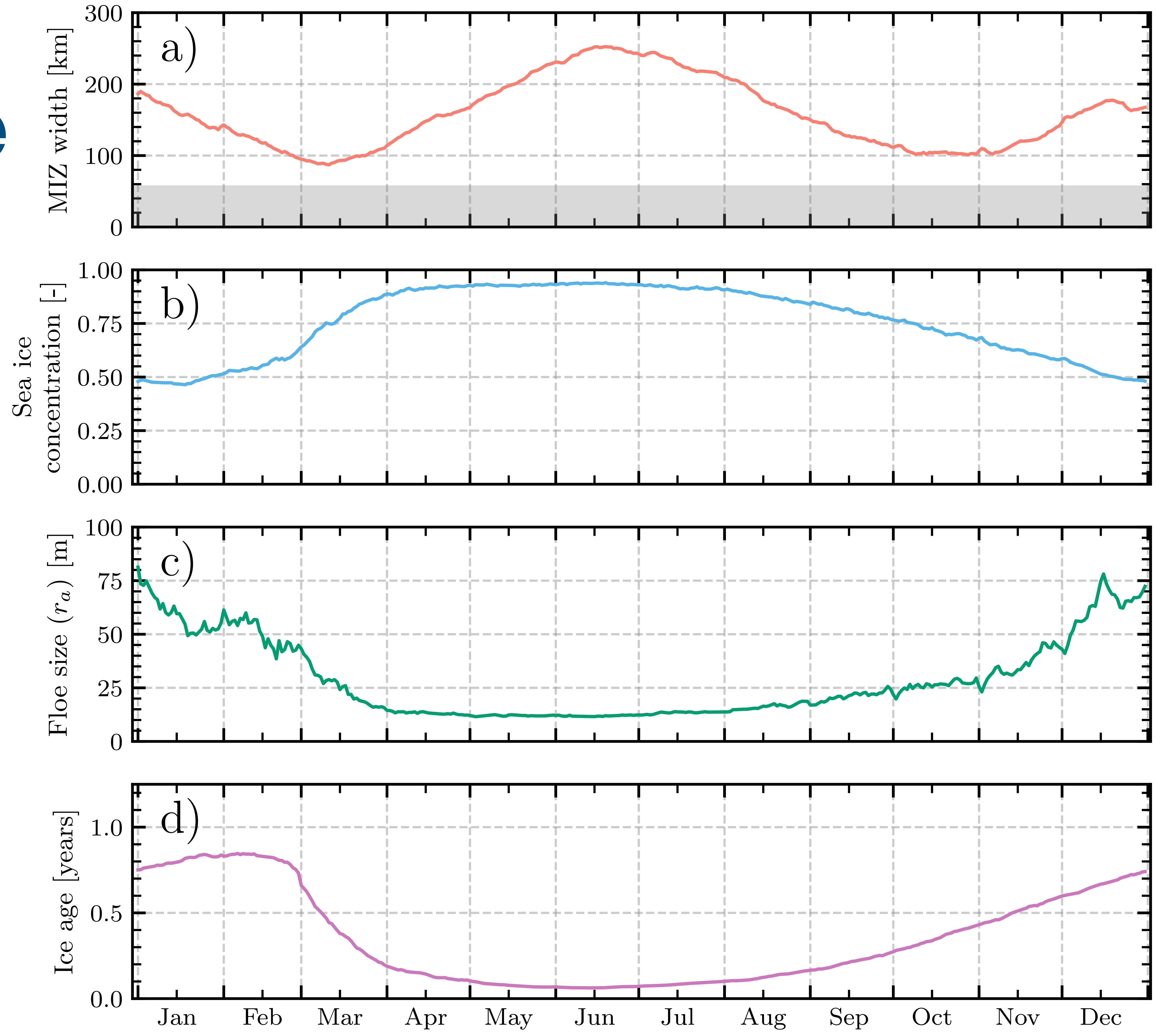


[6] Brouwer et al., *Cryosphere*, 2022

Seasonality of the MIZ properties

❄️ Winter MIZ: high concentrations of small, young floes

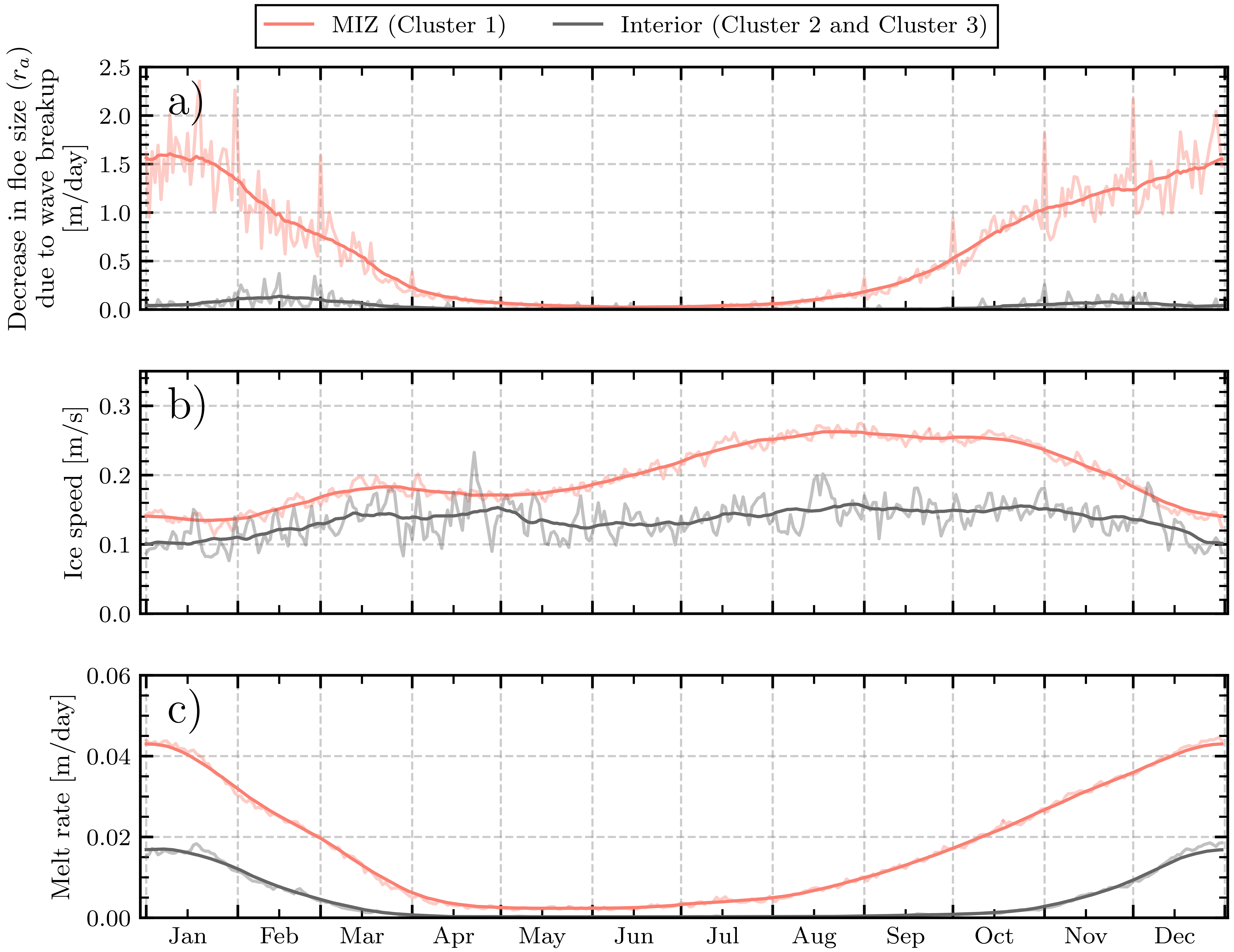
☀️ Summer MIZ: low concentrations of larger, older floes



Climatologies over 2010—2019. Grey shaded region in a) represents the width of a model grid cell.

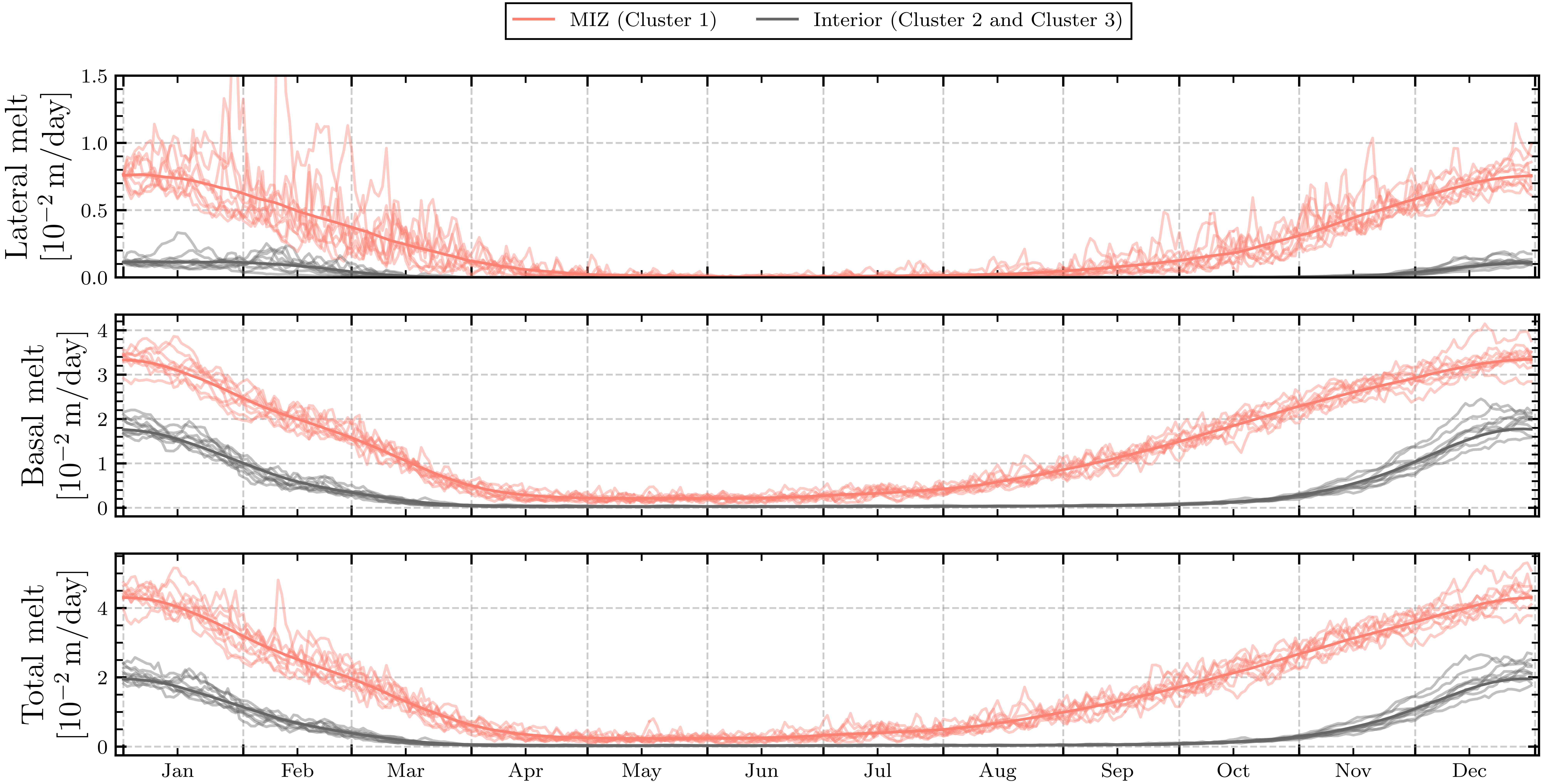
Seasonality of the MIZ processes

- ❄️ Winter MIZ: decreased wave-induced breakup
- 🌱 Spring MIZ: increased drift
- ☀️ Summer MIZ: increased wave breakup and melt rates



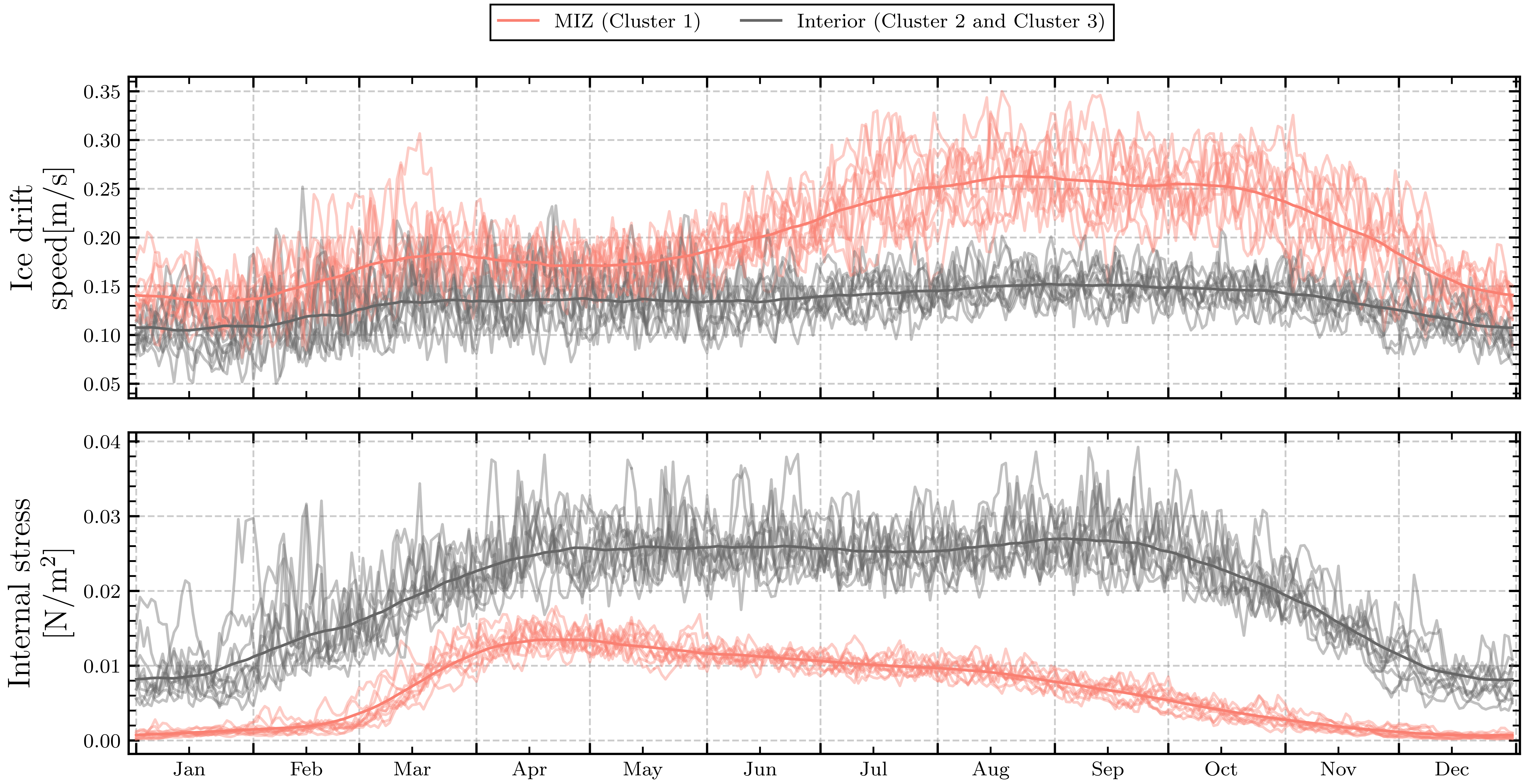
Climatology 2010—2019 (light lines) and 30-day moving average (dark lines).

Seasonality of thermodynamics



Each year in 2010—2019 (light lines) and 30-day moving average (dark lines).

Seasonality of dynamics



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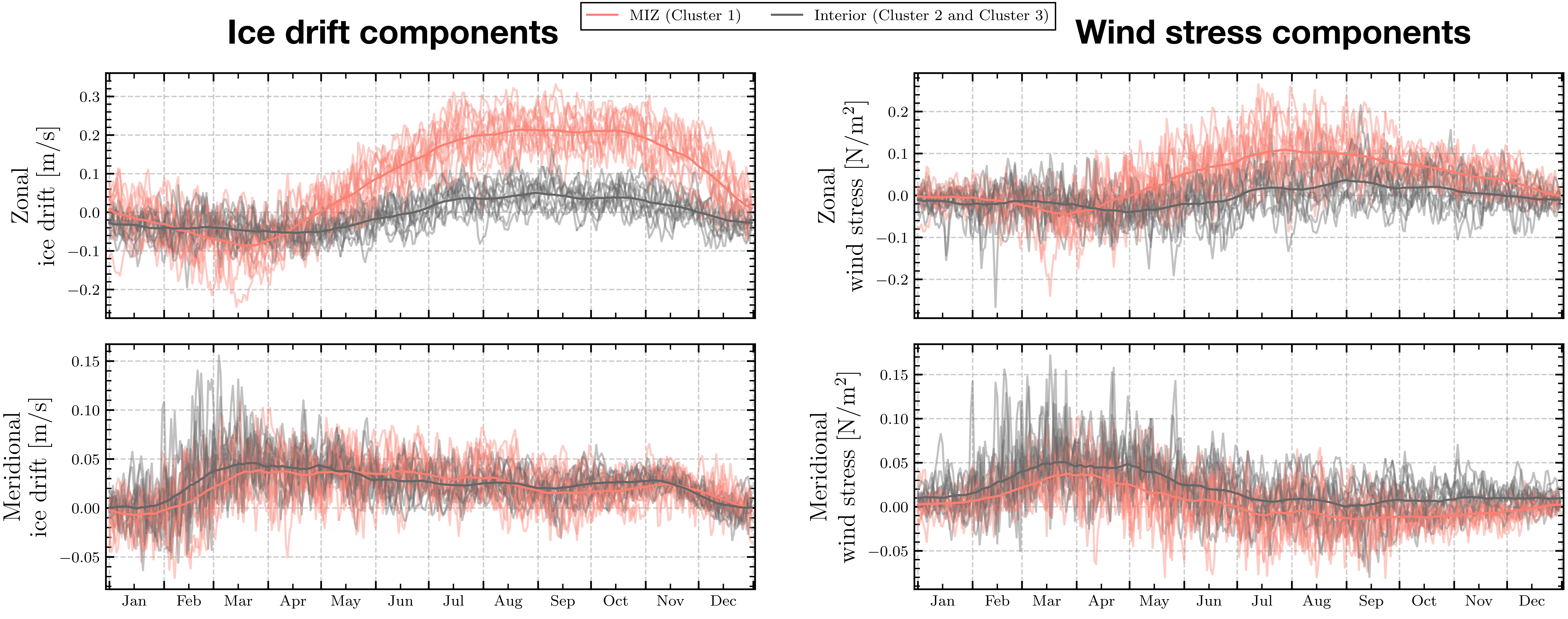


Each year in 2010—2019 (light lines) and 30-day moving average (dark lines).

Summary of study

- An unsupervised algorithm (*k*-means) has quantified the Antarctic wave affected marginal ice zone from simulated sea ice data
- The derived MIZ width agreed with satellite derived waves-in-ice measurements
- The winter MIZ is composed of new pancake floes in high concentrations, the summer MIZ contains larger-broken floes in lower concentrations
- The MIZ undergoes seasonally-dependent physical processes:

  ❄️ Winter: Pancake ice formation

  🌱 Spring: Increased drift

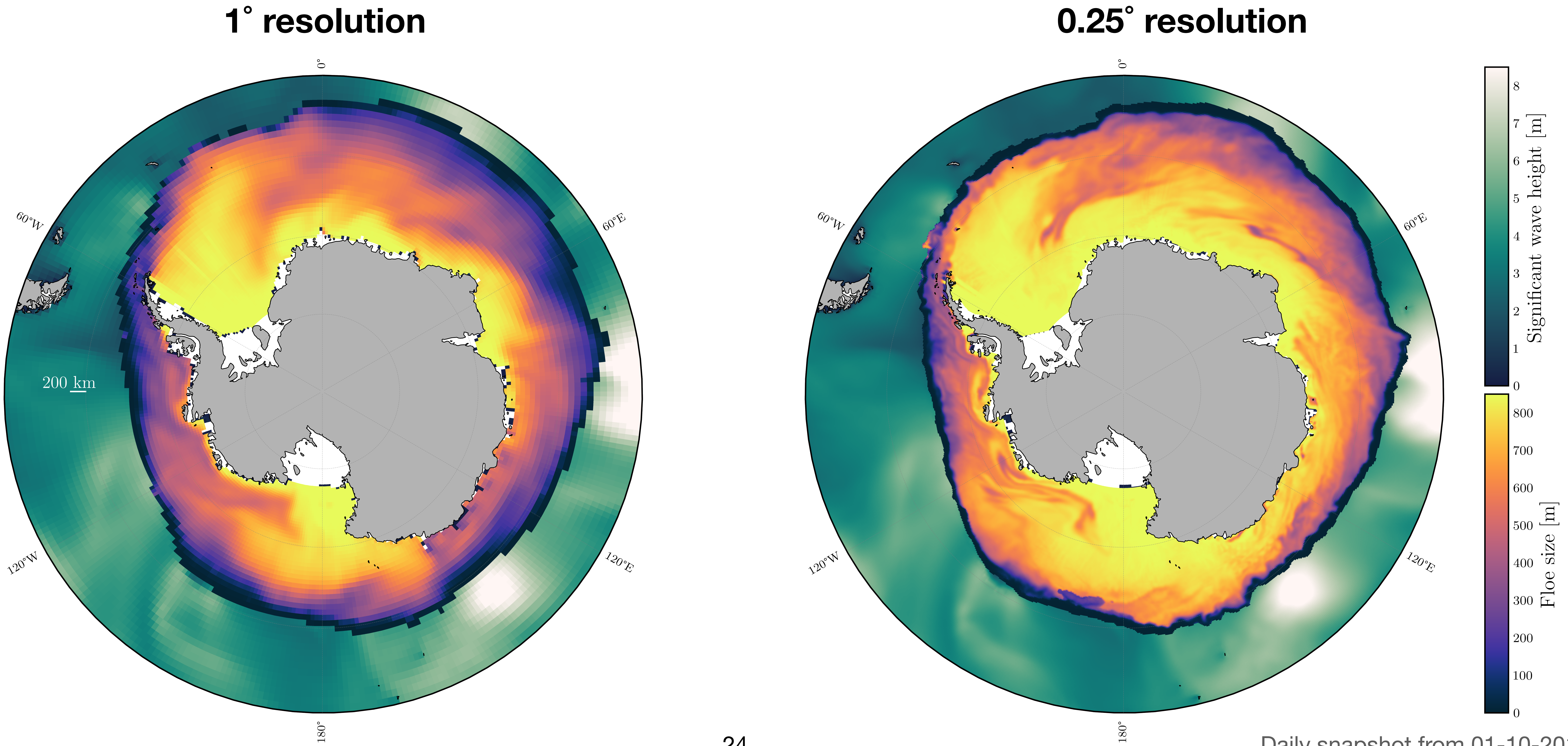
  ☀️ Summer: Increased wave breakup and melt rates

Check out the pre-print!

Day, Bennetts, O'Farrell, et al. *Unsupervised classification of the Antarctic marginal ice zone*. Authorea. 2023.
DOI: 10.22541/au.170147000.07796915/v1

Future work

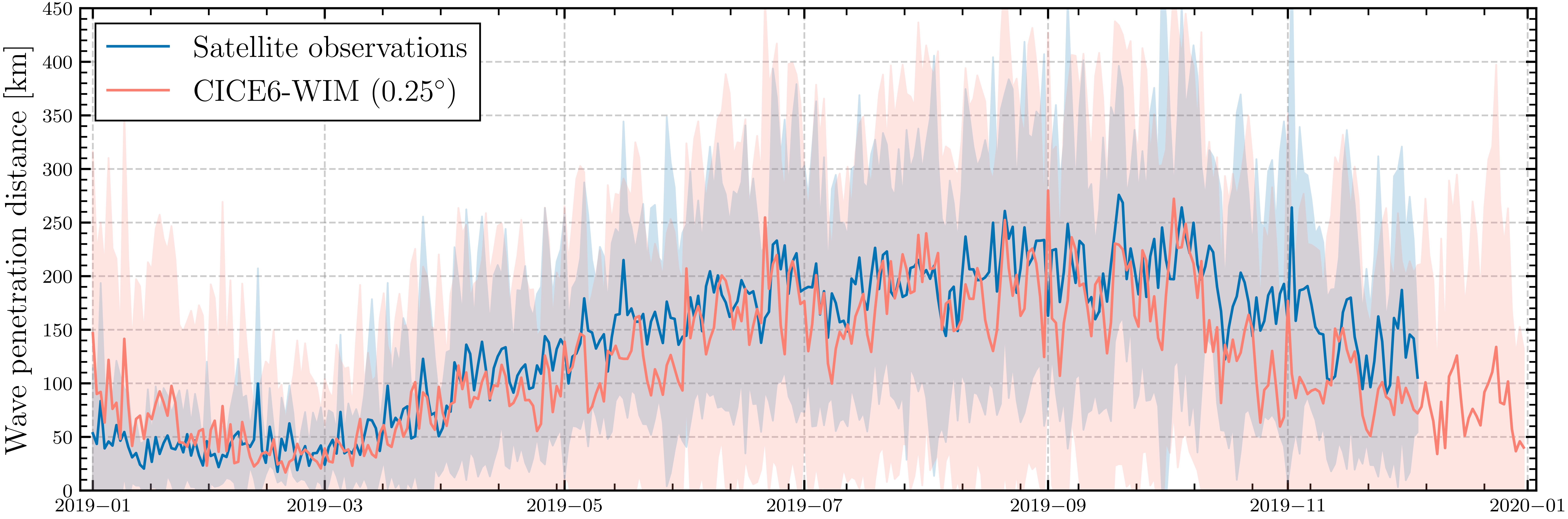
Higher resolution CICE6-WIM simulations



Daily snapshot from 01-10-2019.

A more thorough comparison with observations

- Alex Fraser et al. have now gathered many more observations of MIZ width estimates (i.e., wave penetration distances) than Brouwer et al. (2022)



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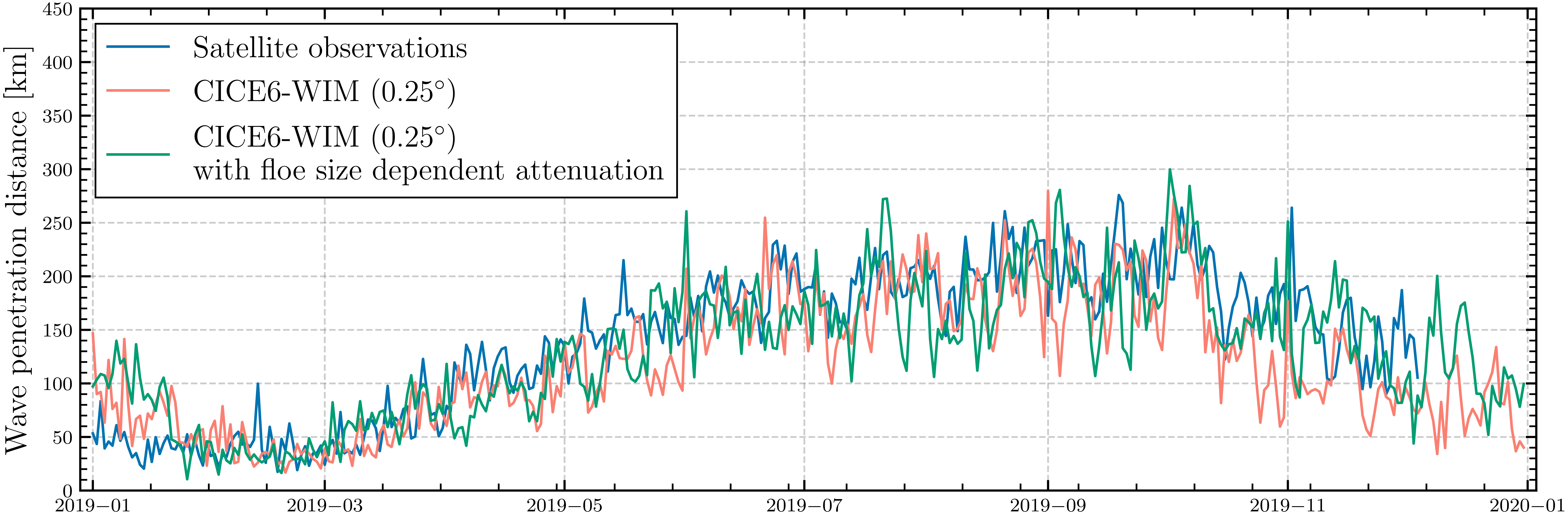
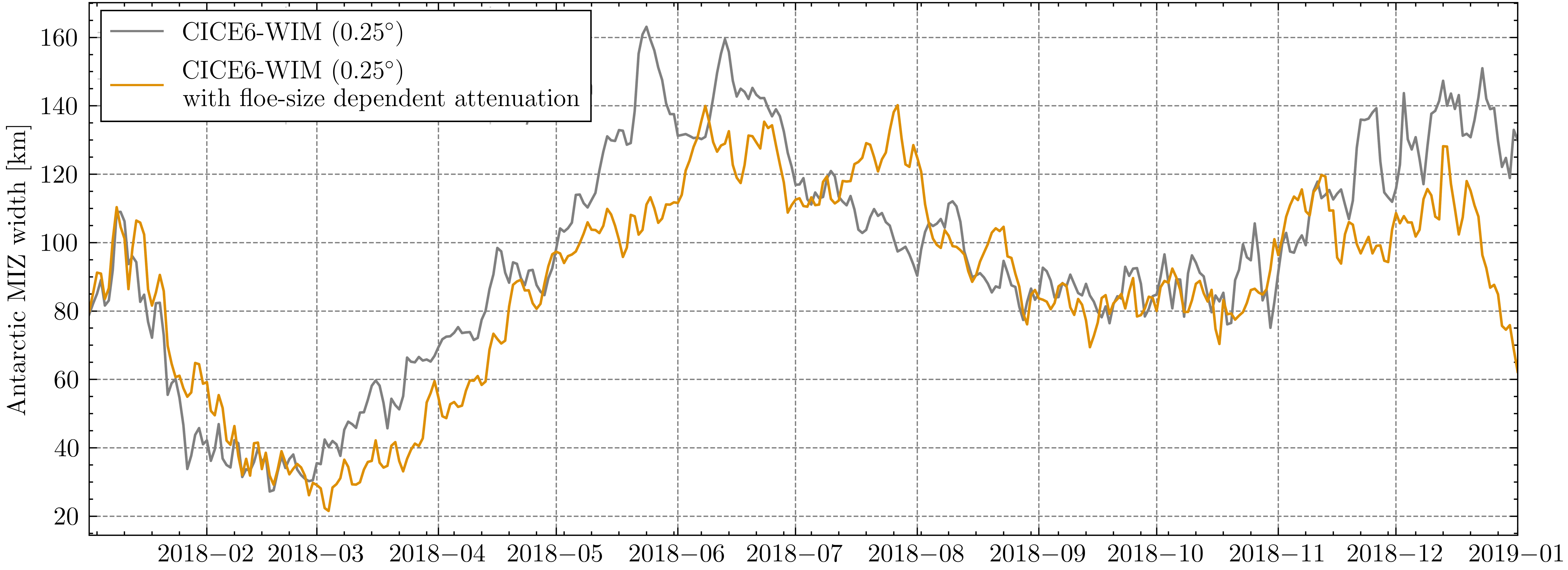


*Floe size dependent attenuation simulation is from 2018

Effect of floe-size dependent attenuation on MIZ widths

- Using a simple floe-size based definition for the MIZ (radius < 20 m)



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- Using a simple floe-size based definition for the MIZ (radius < 20 m)

Our current understanding

- Simple wave-ice attenuation models are producing realistic estimates of circumpolar MIZ width/wave penetration
- However, predicting the width of the MIZ at a particular instance in time or space is still an outstanding problem
- We're looking into what is driving the differences in the MIZ (e.g., the role of polar storms and cyclones) to improve our understanding of the physical processes that create this variability

Thank you!

Contact me at:

noah.day@adelaide.edu.au

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DOI: 10.22541/au.170147000.07796915/v1