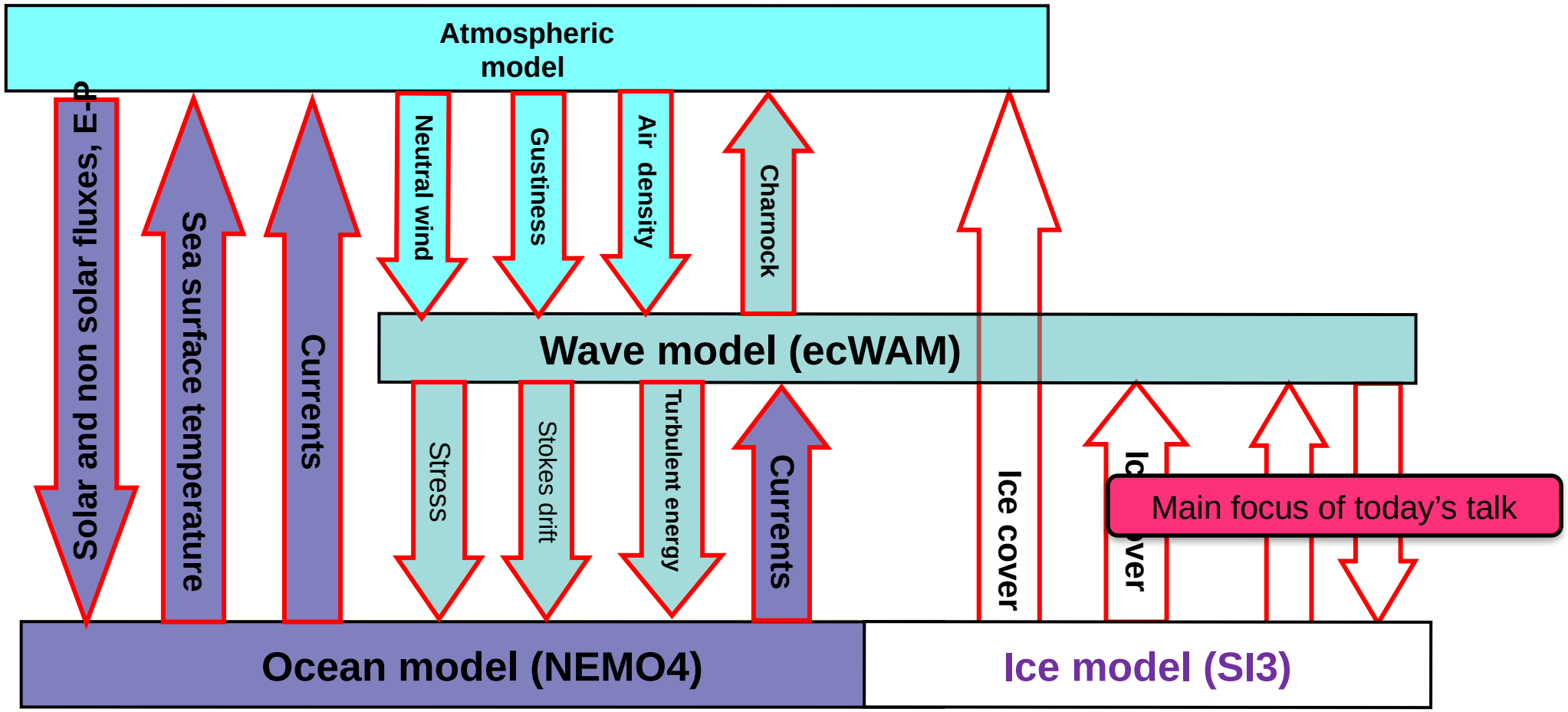
# Wave-Sea Ice Interactions in the IFS

**Josh Kousal,** Jean Bidlot, Charles Pelletier, Sarah Keeley, Kristian Mogensen



# The IFS
# (a simplified view of the forecast system)




CY50R1

# Outline

- Waves in sea ice in CY50R1 (operational cycle, May 2026)

- Two-way wave-sea ice coupling (a future cycle)

# Attenuation

## *attenuation of waves by sea ice*

- Waves are attenuated in the sea ice due to processes such as scattering, under-ice friction, in-ice friction, …

- Attenuation of waves by sea ice is generally represented as

$$S_{ice} = -2 C_g k_i E$$

$$k_i(f) \propto f^n$$

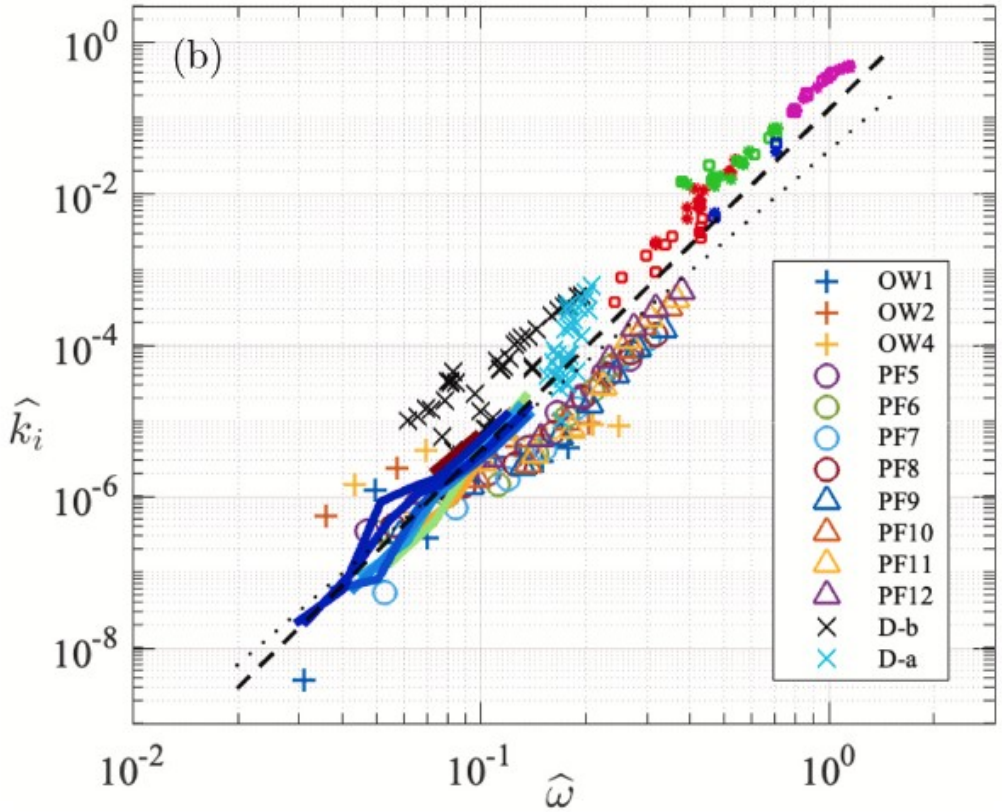
- Yu et al. (2022) model (hereafter YEA22)

A new method for parameterization of wave dissipation by sea ice

Jie Yu *, W. Erick Rogers, David W. Wang

*Naval Research Laboratory, Stennis Space Center, MS 39529, USA*

$$k_i = C h_{ice}^{1.25} f^{4.5}, \quad \text{where} \quad C = 0.1274 \left(2\pi/\sqrt{g}\right)^{4.5}$$




Yu et al. (2022)
https://doi.org/10.1016/j.coldregions.2022.103582

# Wave-Sea ice coupling in the ECMWF earth system model

Operational setup for 2025* (CY49R1**)

**ecWAM (wave model)**
- : no wave attenuation by sea ice
- : wave model masked; full wave attenuation by sea ice

**LIM2 (sea ice model)**




= sea ice concentration
= sea ice thickness
= sea ice thickness
= wave number, imaginery
= wave frequency
= gravity

*New operational cycles are usually introduced every year in November
**CY49R1 was implemented in November, 2024

# Wave-Sea ice coupling in the ECMWF earth system model

Current operational setup (CY50R1)

**ecWAM (wave model)**

*New features*

- Wave in sea ice attenuation routine

**SI3 (sea ice model)**

Effect

- wave attenuation

= sea ice concentration
= sea ice thickness
= sea ice thickness
= wave number, imaginery
= wave frequency
= gravity

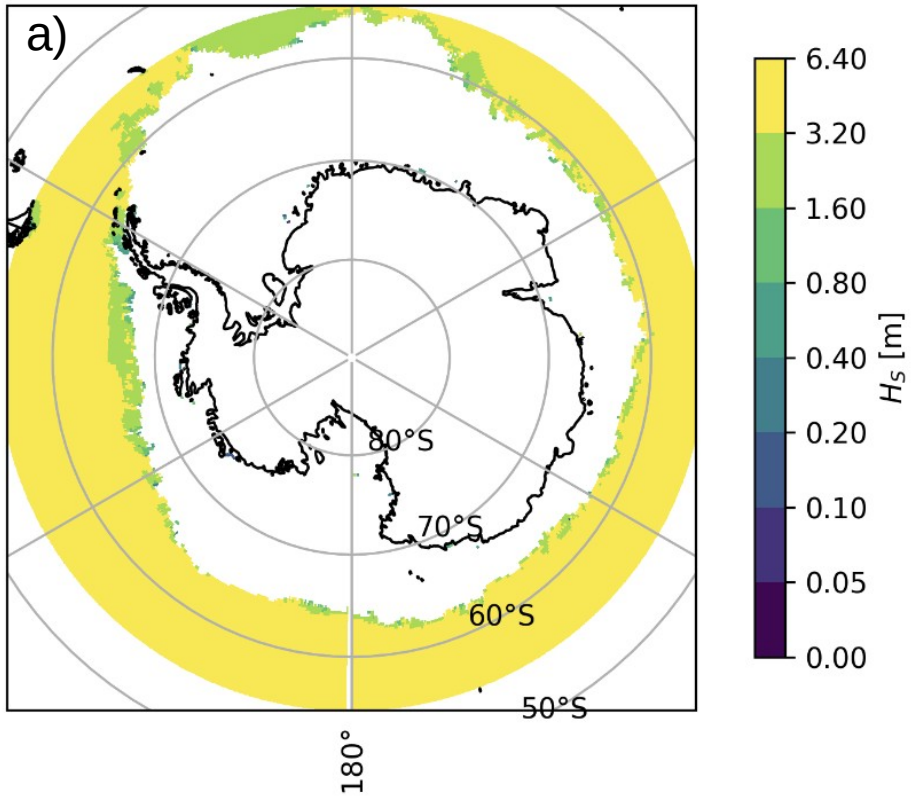
denotes Yu et al. (2022), in which the attenuation coefficient of waves in sea ice is given by

$$k_i = C h_{ice}^{1.25} f^{4.5}, \quad \text{where} \quad C = 0.1274 \left(2\pi / \sqrt{g}\right)^{4.5}$$

DOI: 10.1016/j.coldregions.2022.103582

# Effect on the Antarctic is a similar story

Operational setup for 2025 (CY49R1)

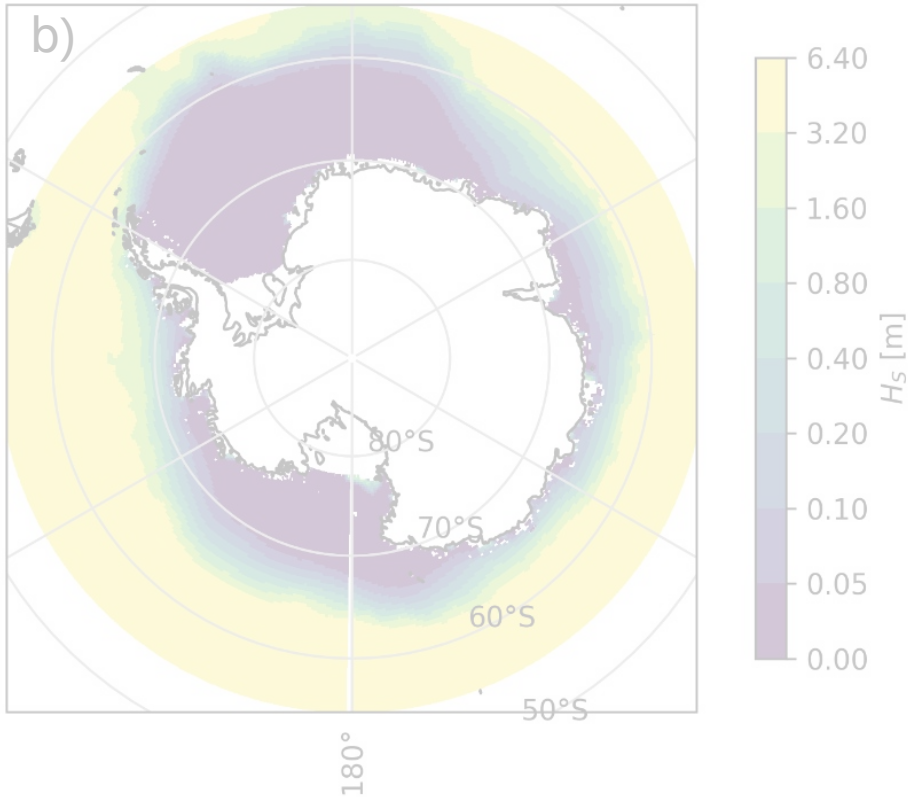



**CY49R1**

SIC<30%: No attenuation of waves by sea ice

SIC>30%: Wave model turned off; full blocking

Operational setup for 2026 (CY50R1)



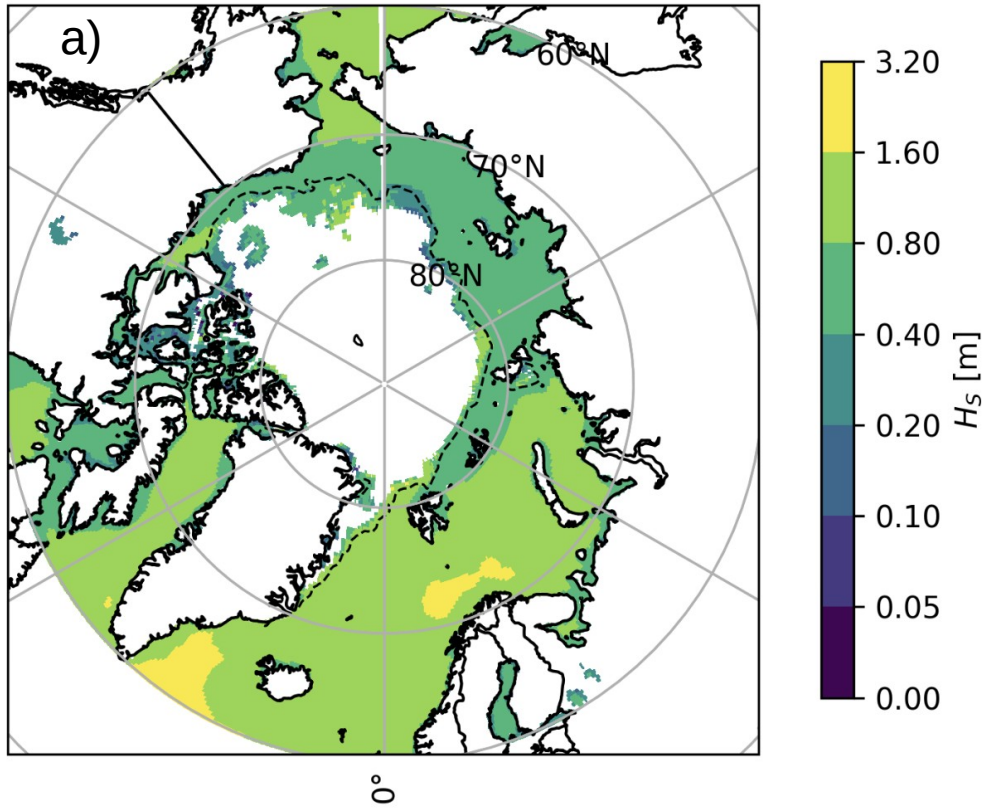

**CY50R1**

Stop blocking for SIC>30%

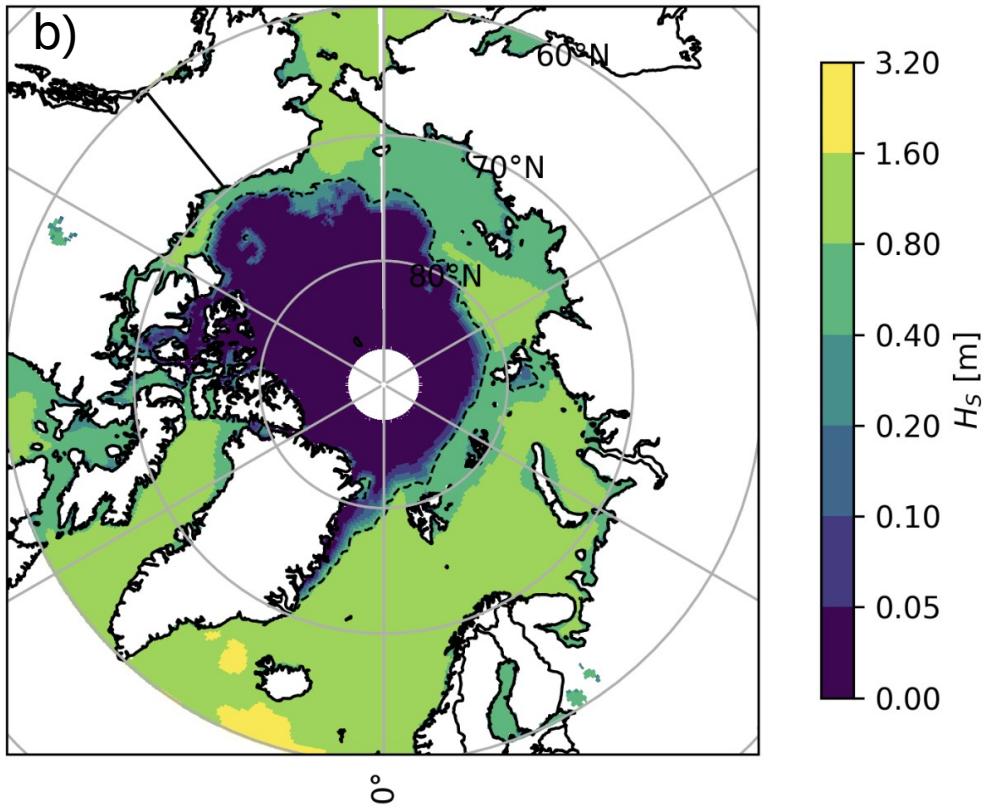
Activate attenuation

# Significant Wave Height

Operational setup for 2025 (CY49R1)




Current operational setup (CY50R1)




**CY49R1**

SIC<30%: No attenuation of waves by sea ice

SIC>30%: Wave model turned off; full blocking

**CY50R1**

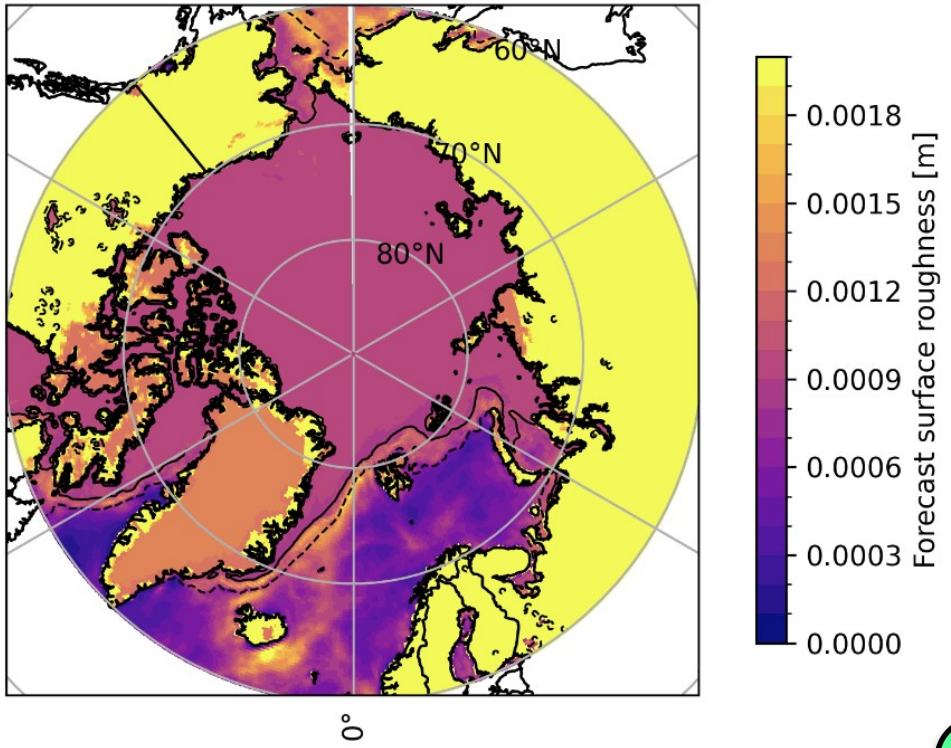
Stop blocking for SIC>30%

Activate attenuation

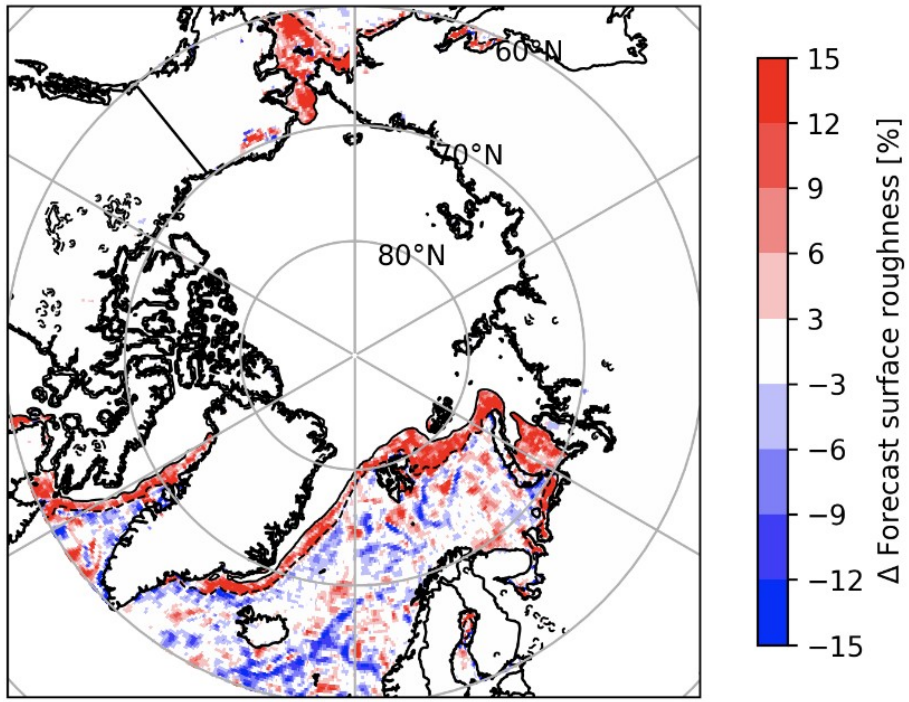
# Forecast Surface Roughness

*Combined roughness between the water and the sea ice tiles*

Field




Difference



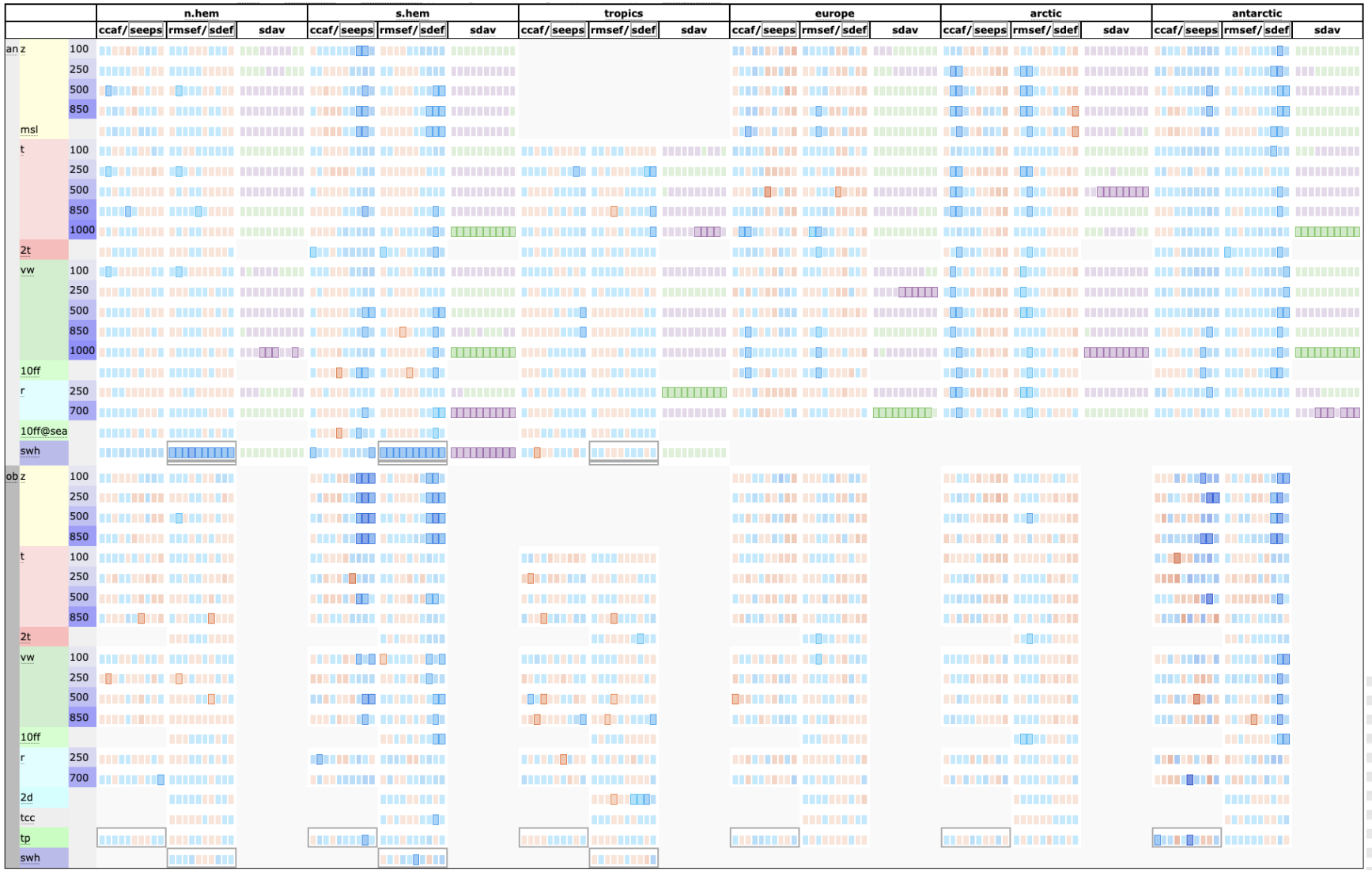

- Snapshot for: Date 2022-12-10- 2023-01-10, forecast lead time T+48 hours
- Black contour shows 15% and 85% SIC

- Waves in sea ice increases surface roughness due to existing wave-to-atmosphere coupling (through the increase in the Charnock parameter).
- This is the driver of impacts on the coupled system

# Effect of waves in sea ice on the coupled system

vs. analysis

vs. observations








# Verification of waves in sea ice – Norwegian buoy campaigns

Newsletter

Number 185 - Autumn 2025

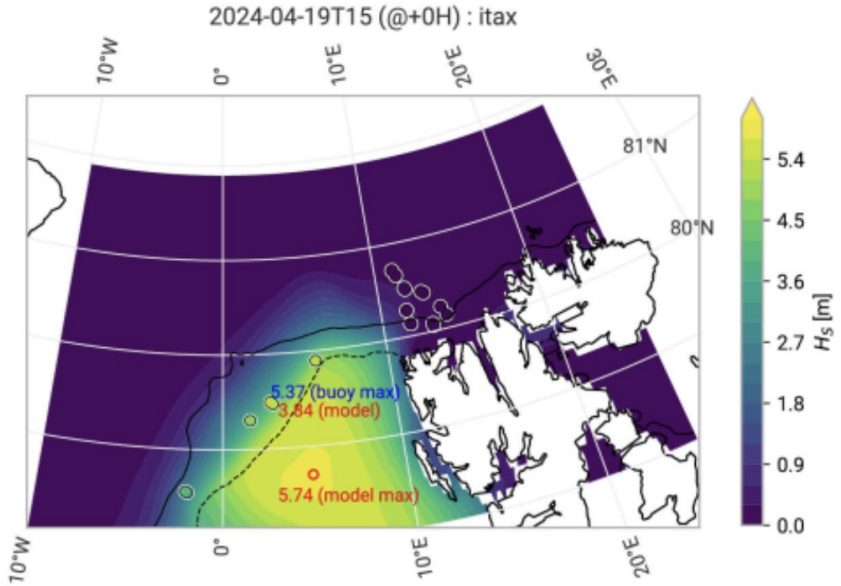
Published in October 2025

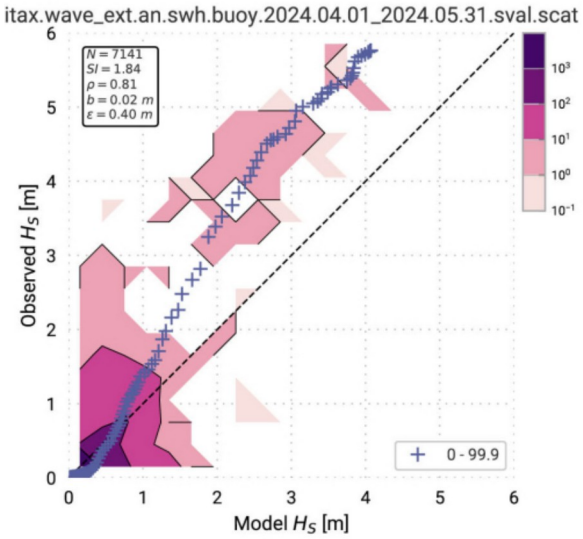
NEWS The introduction of waves in sea ice

◄ View all Newsletters

Editorial

Josh Kousal, Jean Bidlot, James Steer (all ECMWF),
Jean Rabault (Norwegian Meteorological Institute),
Malte Müller (Norwegian Meteorological Institute and The University of Oslo)



# Outline

- Waves in sea ice in CY50R1 (operational cycle, May 2026)

- **Two-way wave-sea ice coupling (a future cycle)**

# Sea ice break up
## *wave-induced sea ice break up*

- waves propagating through a sheet of continuous sea ice can break it into a series of smaller floes

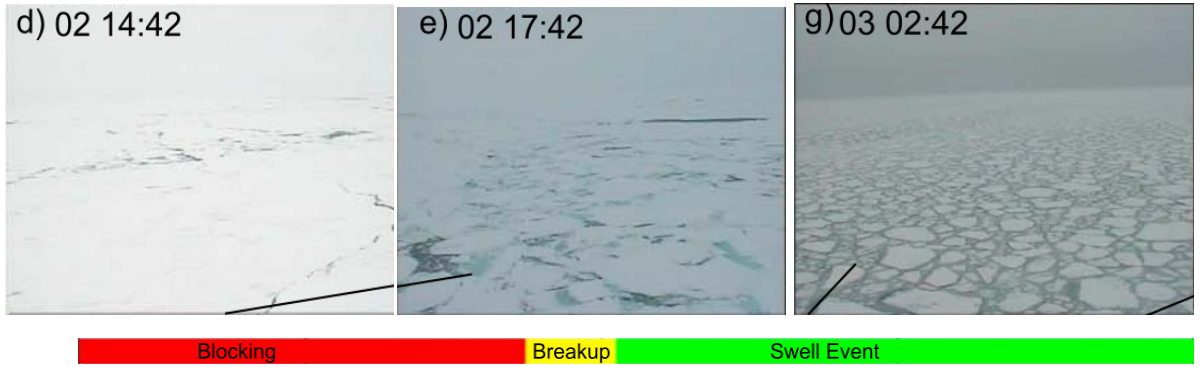



**Fig. 5.** Observed wave height (solid line; left) and sea ice (right) and during a break up event [4]

[4]Collins et al. (GRL 2015), [5]Ardhuin et al. (GRL 2020), [6]Voermans et al. (TC 2021)

# Sea ice break up

## *wave-induced sea ice break up*

The Cryosphere, 14, 4265–4278, 2020
https://doi.org/10.5194/tc-14-4265-2020
© Author(s) 2020. This work is distributed under
the Creative Commons Attribution 4.0 License.

The Cryosphere Open Access EGU

**Experimental evidence for a universal threshold characterizing wave-induced sea ice break-up**

**Joey J. Voermans[1], Jean Rabault[2,3], Kirill Filchuk[4], Ivan Ryzhov[4], Petra Heil[5], Aleksey Marchenko[6], Clarence O. Collins III[7], Mohammed Dabboor[8], Graig Sutherland[9], and Alexander V. Babanin[1,10]**

$$I_{\mathrm{br}} = \frac{a h_i Y}{\sigma \lambda^2}$$

$$I_{\mathrm{br_crit}} = 0.014$$

The sea ice at any point is classed as “broken” when it exceeds its critical threshold, i.e. when

$$I_{br} > I_{br_{crit}}$$

# Sea ice break up AND Attenuation

- waves propagating through a sheet of continuous sea ice can break it into a series of smaller floes
- ***sea ice state*** (i.e. whether the ice is broken) ***is a dominant process in wave attenuation***[4,5,6]

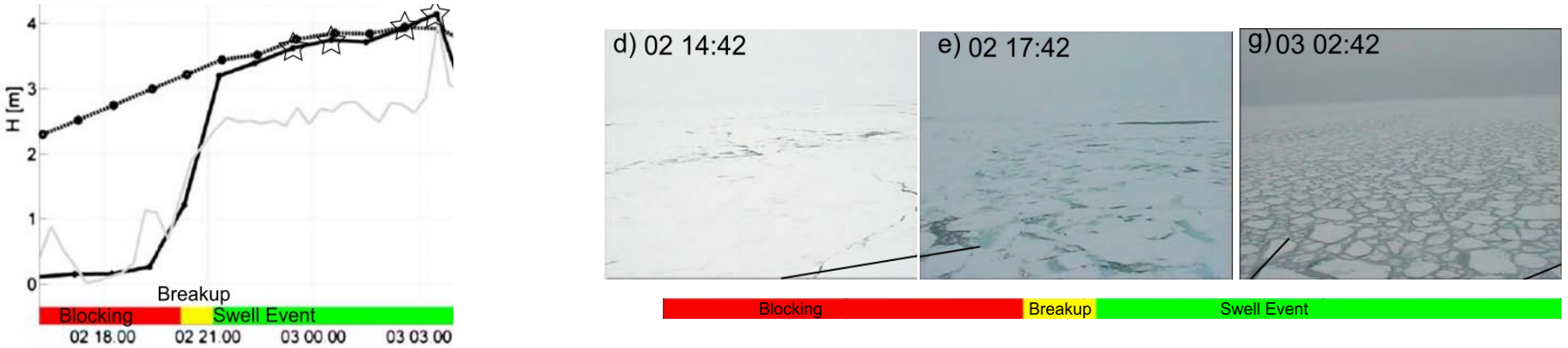


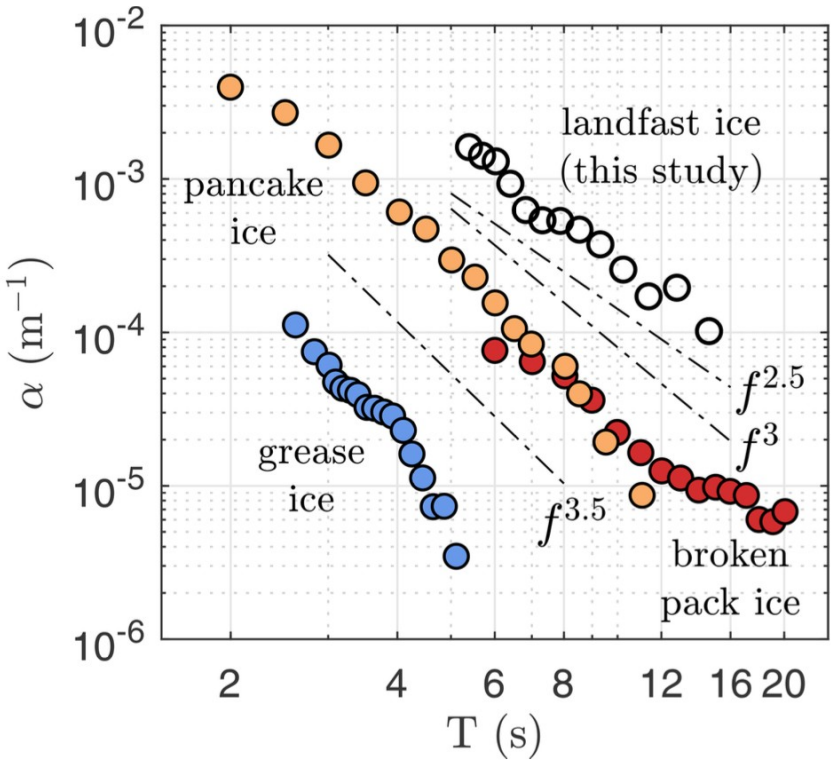

**Fig. 5.** Observed wave height (solid line; left) and sea ice (right) and during a break up event [4]

[4]Collins et al. (GRL 2015), [5]Ardhuin et al. (GRL 2020), [6]Voermans et al. (TC 2021)

$H = significant\ wave\ heigh$

# Sea ice break up AND Attenuation

- waves propagating through a sheet of continuous sea ice can break it into a series of smaller floes
- ***sea ice state*** (i.e. whether the ice is broken) ***is a dominant process in wave attenuation***[4,5,6]




**Wave dispersion and dissipation in landfast ice: comparison of observations against models**


Joey J. Voermans[1], Qingxiang Liu[2,1], Aleksey Marchenko[3], Jean Rabault[4,5], Kirill Filchuk[6], Ivan Ryzhov[6], Petra Heil[7], Takuji Waseda[8], Takehiko Nose[8], Tsubasa Kodaira[8], Jingkai Li[2], and Alexander V. Babanin[1,9]

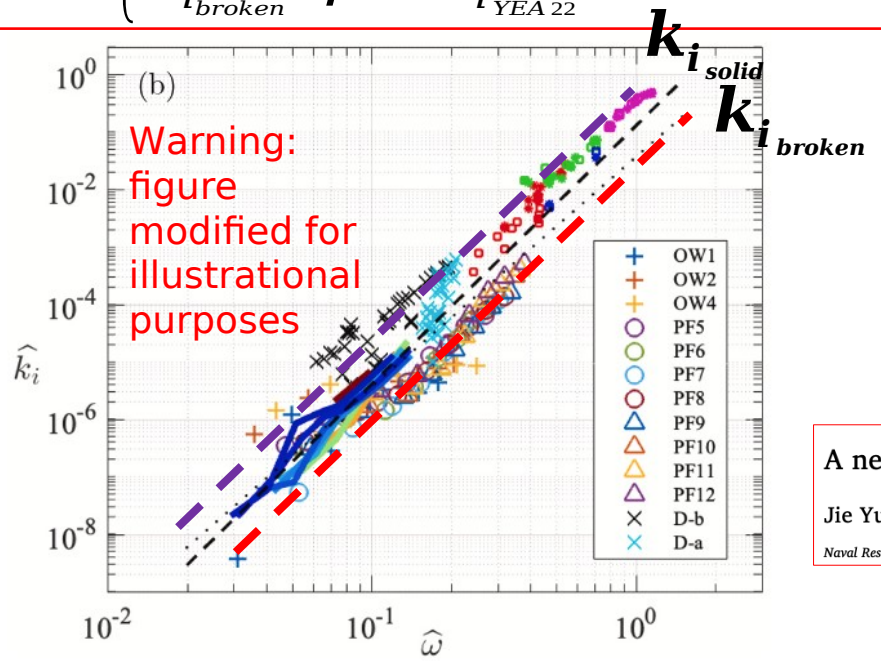

[4]Collins et al. (GRL 2015), [5]Ardhuin et al. (GRL 2020), [6]Voermans et al. (TC 2021)

# Sea ice break up AND Attenuation

- We can modify the YEA22 formulation to account for sea ice state (i.e. broken/solid) in the following way

$$k_{i_{YEA\,22}} = ¿\, C h_{ice}^{1.25} f^{4.5}, \quad \text{where} \quad C = 0.1274\left(2\pi/\sqrt{g}\right)^{4.5}$$

$$k_i = \begin{cases} k_{i_{solid}} : \beta\, k_{i_{YEA\,22}} \\ k_{i_{broken}} : \beta^{-1} k_{i_{YEA\,22}} \end{cases}, \beta^2 = \vartheta(10)$$




A new method for parameterization of wave dissipation by sea ice

Jie Yu *, W. Erick Rogers, David W. Wang

*Naval Research Laboratory, Stennis Space Center, MS 39529, USA*

Yu et al. (2022)
https://doi.org/10.1016/j.coldregions.2022.103582

# Wave-Sea ice coupling in the ECMWF earth system model

Experimental setup

Effect
- sea ice break up
- wave radiative stress

**ecWAM (wave model)**

*New features*

- Wave in sea ice attenuation routine
- Attenuation modified by sea ice state

**SI3 (sea ice model)**

*New features*

- Prognostic sea ice breakup memory
- Reduced ice strength for broken sea ice

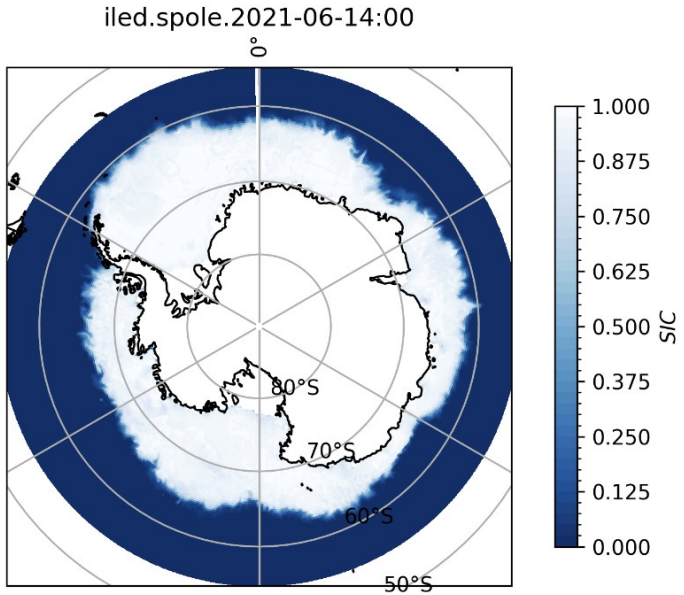
Effect
- wave attenuation

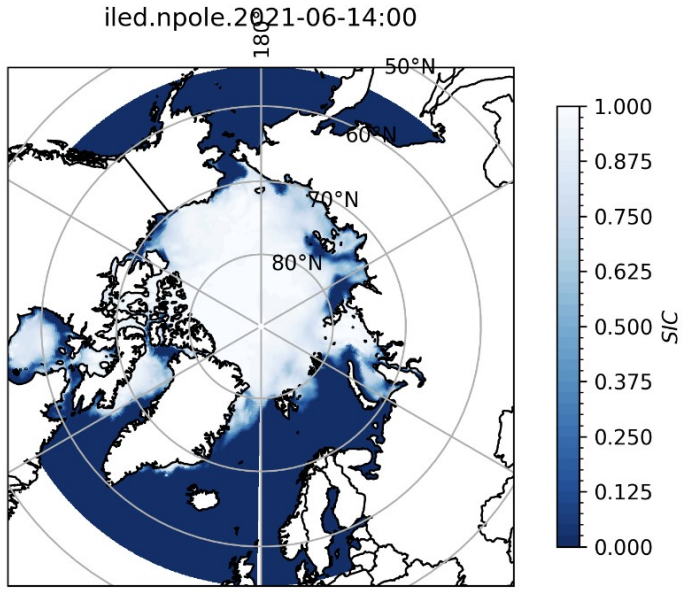
$$k_i = \begin{cases} k_{i_{solid}} : \beta k_{i_{YEA\,22}} \\ k_{i_{broken}} : \beta^{-1} k_{i_{YEA\,22}} \end{cases}, \beta^2 = \vartheta(10)$$

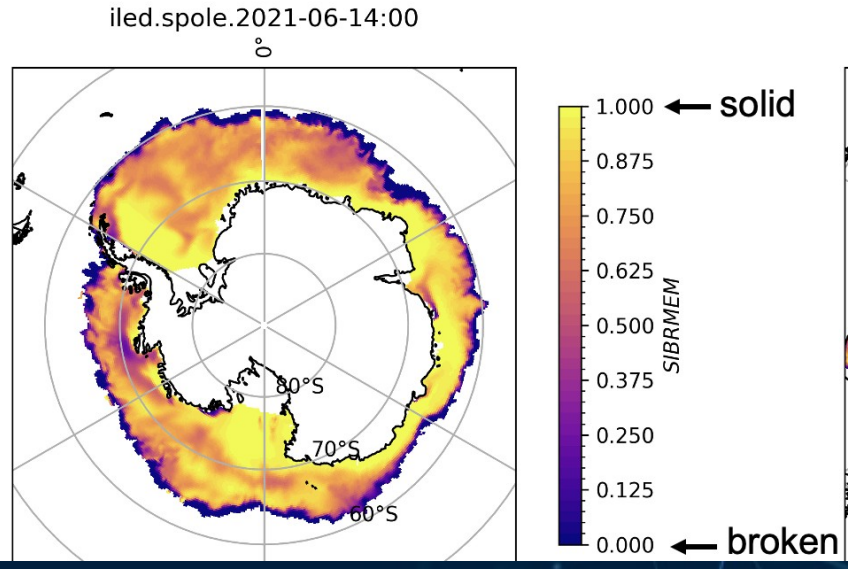
- Wave-induced sea-ice break up stays in memory
- New prognostic field within SI3
- “Healed” by new ice formation

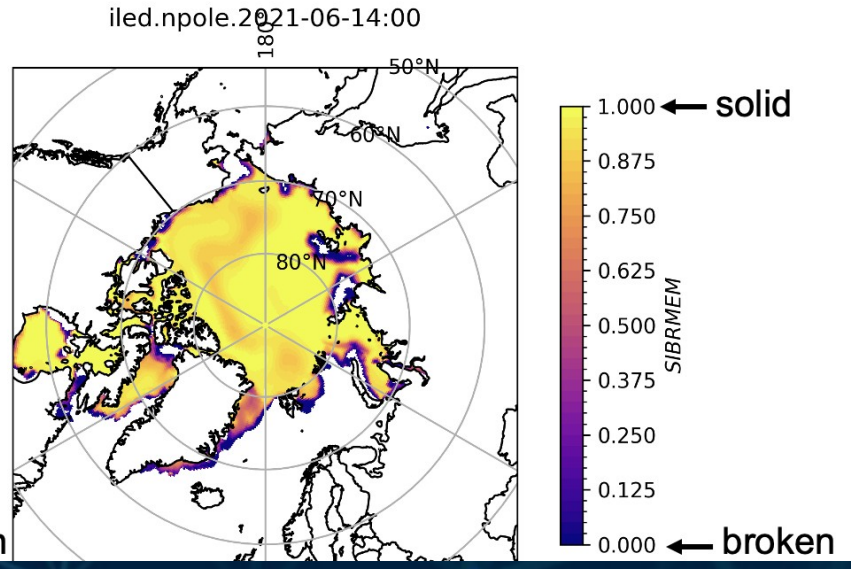
# What does this look like?

ORAS6-type exp (single member) + wave-sea ice
(needed for SIMEM initial conditions)



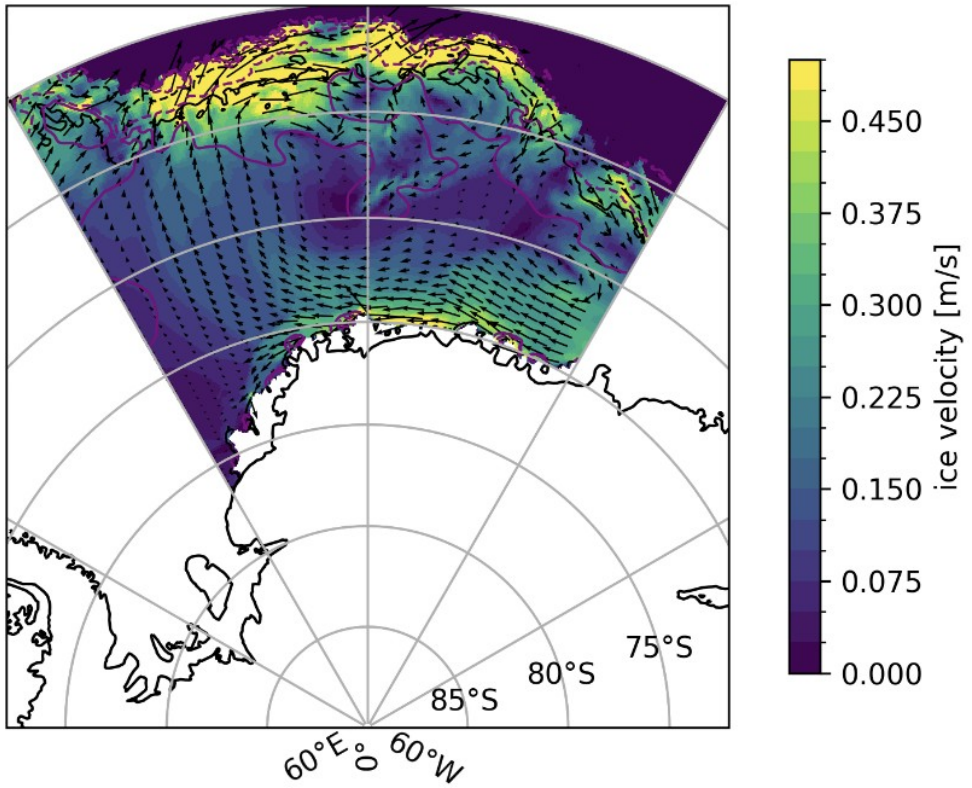



# Implementing two-way interactions between waves and sea ice into the IFS

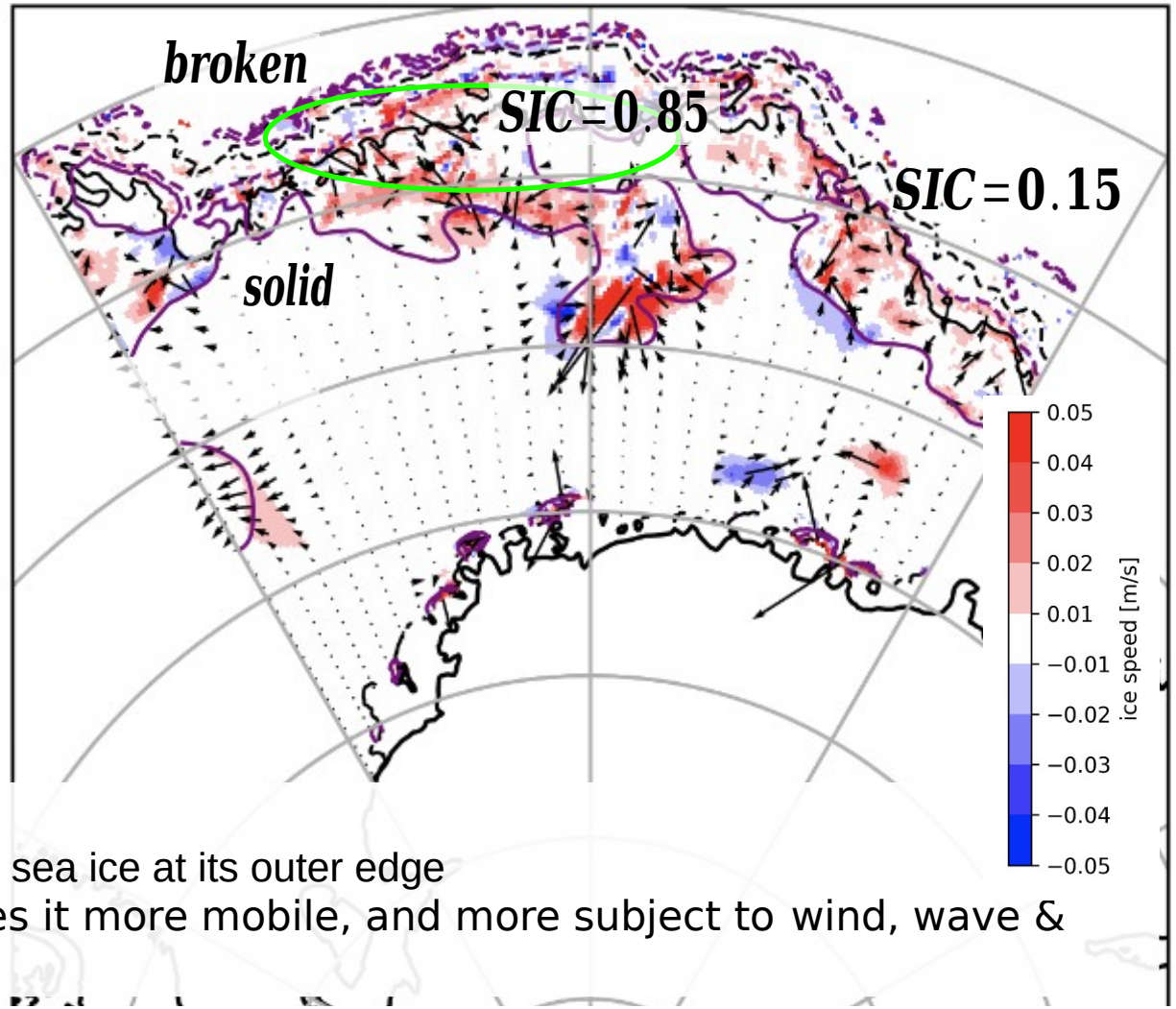
Forecast, T+48

Illustration through case study

**sea ice velocity** (control)




**changes in sea ice velocity** (exp. minus control)




What can we see?

- Waves from the Southern Ocean have broken up the sea ice at its outer edge
- Reduced ice strength for ‘broken’ sea ice makes it more mobile, and more subject to wind, wave & ocean stresses

# Summary

- Waves in sea ice in CY50R1 (operational cycle, May 2026)
  - The introduction of waves in sea ice marks a qualitative change for our system – producing wave fields where we had none before
  - Due to the wave coupling that is already present within the IFS, this has impacts already on the coupled system (through the increase in Charnock and surface roughness in the MIZ)

- Two-way wave-sea ice coupling (a future cycle)
  - New prototype model with two-way coupled interactions between waves and sea ice
  - Still exploring coupled wave-sea ice interactions and their broader effect