Laboratory Experiments on Internal Solitary Waves in Ice-Covered Waters

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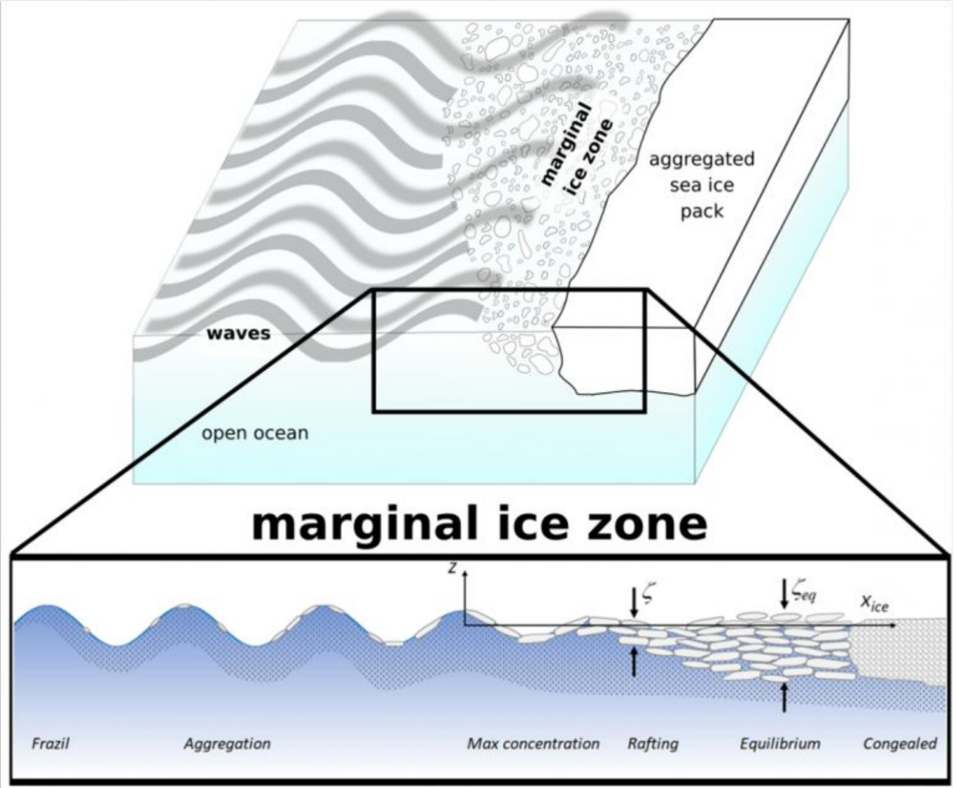
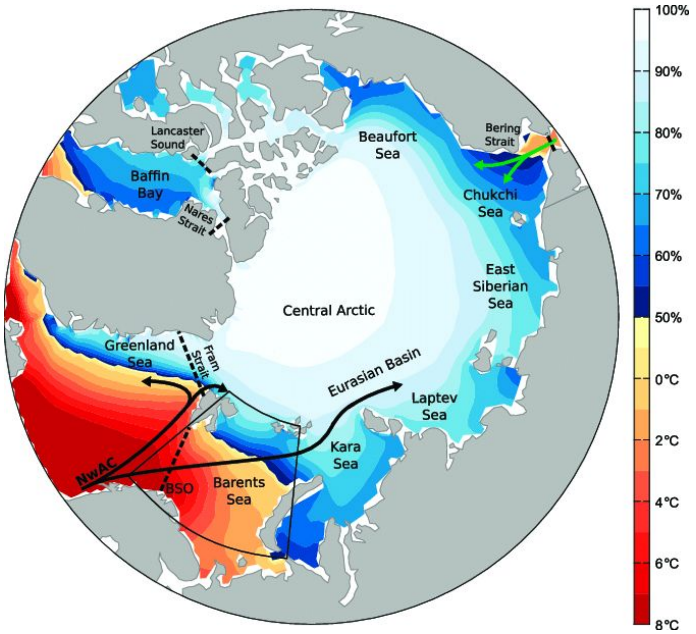


Dai et al. (2019) and Sutherland and Dumont (2018)

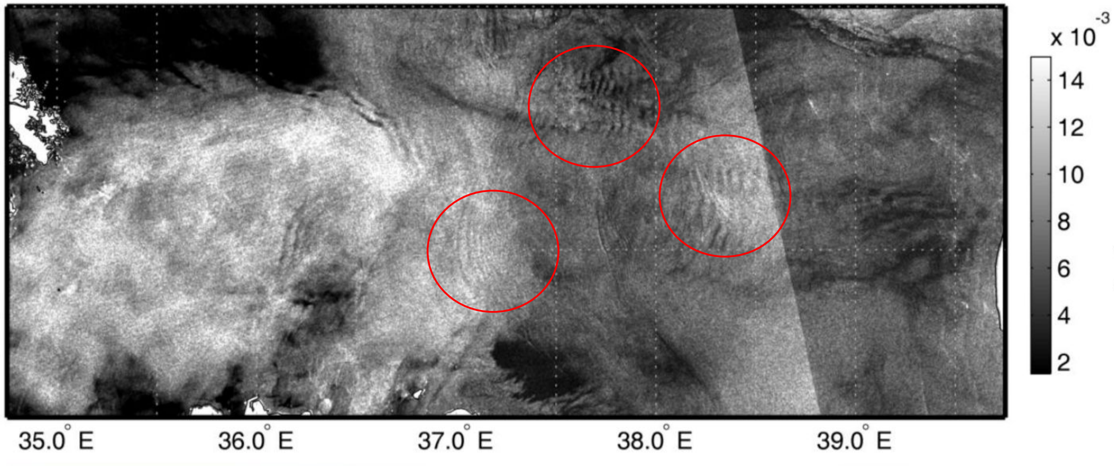


Årthun et.al 2019

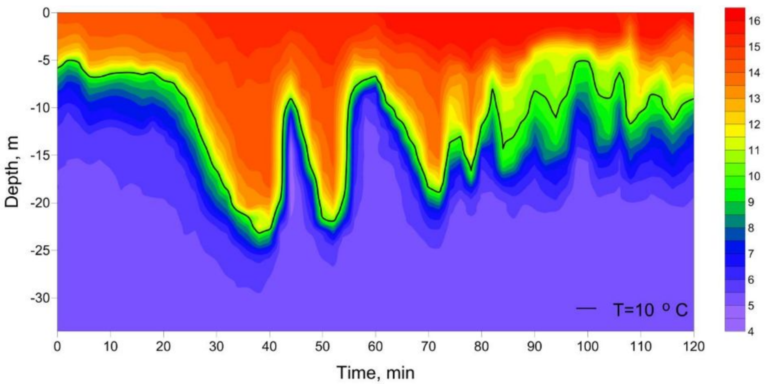
Theory & Field Observations - mapping of internal waves

Field work

Kozlov et.al 2014 ➔ ISW map
Rippeth et.al 2017 ➔ Mixing
Levine et.al 1985 ➔ Turbulence



Kozlov et.al 2014

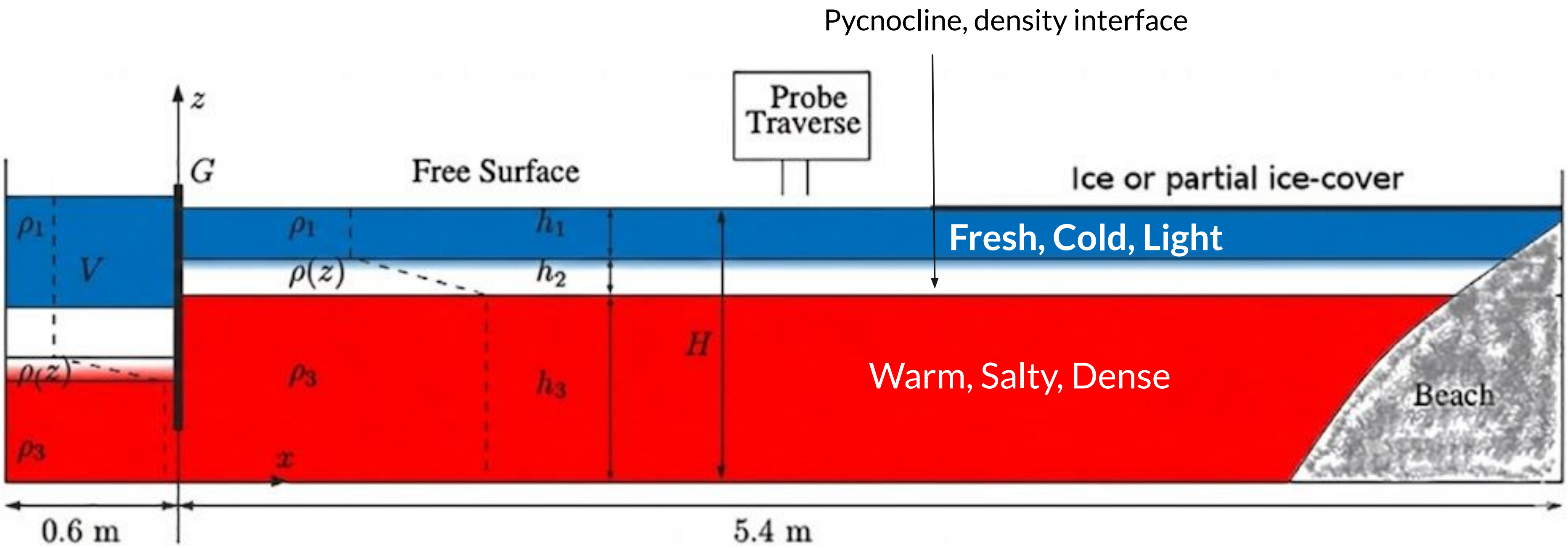


Theory

Muench et.al 1983 ➔ Ice bands
Saiki et.al 2016 ➔ ISW > flexure of ice

Experimental Setup

Arctic environment test basin



Carr et.al 2022

?

What happens if there is an ice edge ? How do ice/ISW interact ? Is ice transported ?

ISW generation

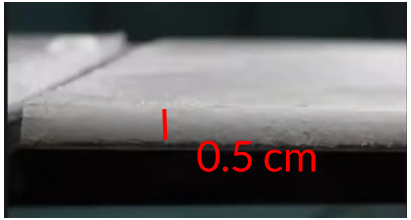
https://www.youtube.com/watch?v=yv2_hfr1wFI

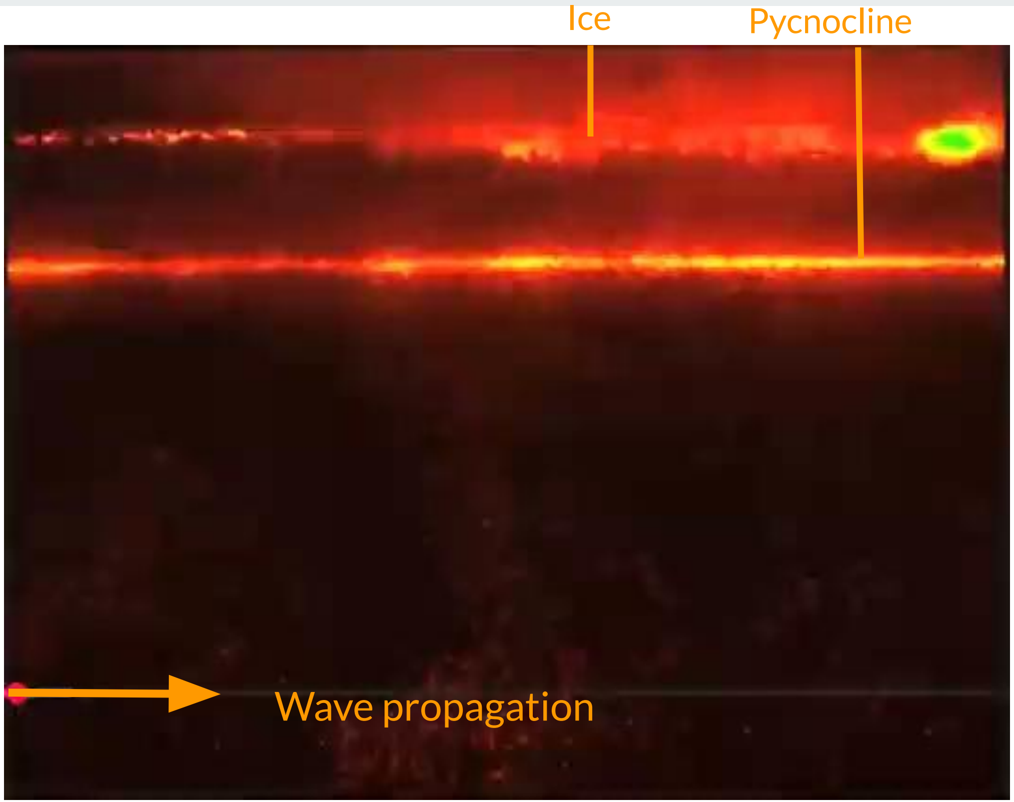
Ice-wave interaction monitored

Grease ice

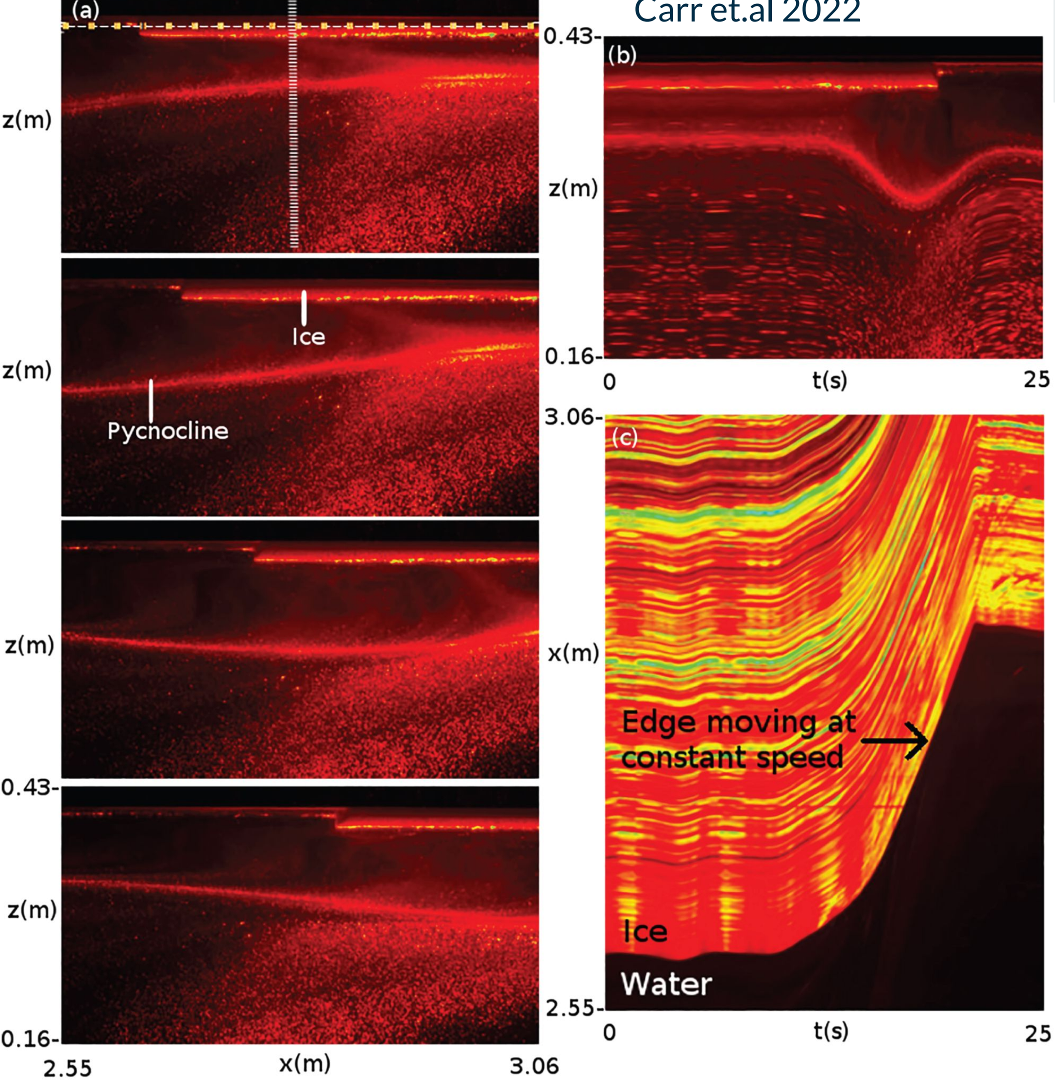
Nilas ice

Sheet ice





https://www.youtube.com/watch?v=yv2_hfr1wFI

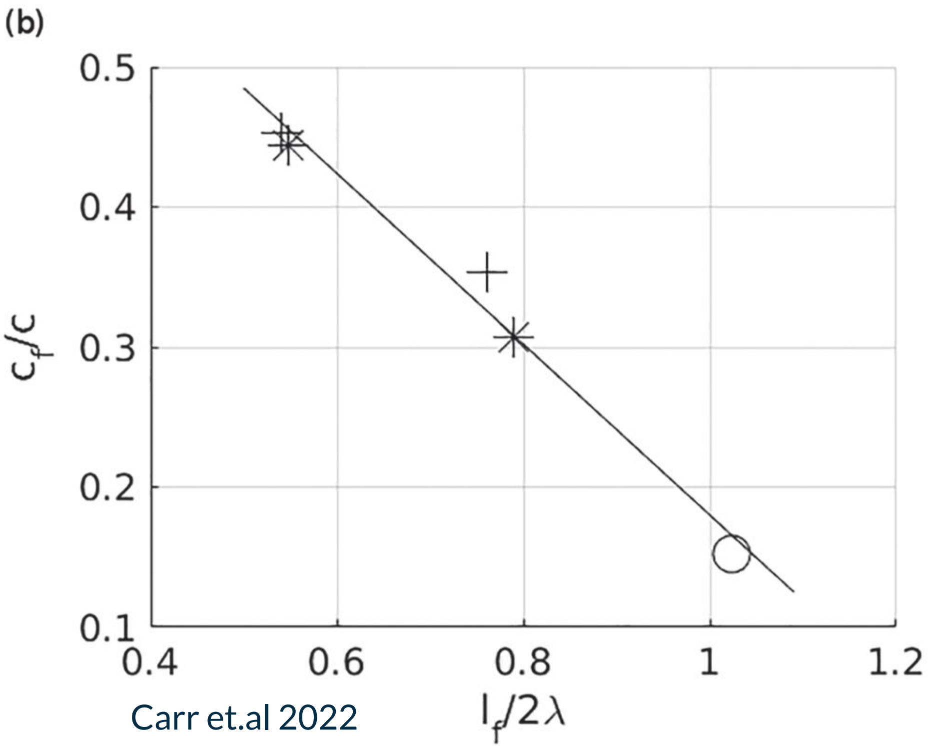


Processing movies

- ➔ c,a, λ : wave characteristics
- ➔ c_f : floe speed

? What relation between floes' sizes and speed ?

Results - Ice floe wave induced motion



Carr et.al 2022

○ Sheet ice, (l_f, d_f) = (2.00m, 0.058m)

+ Sheet ice, (l_f, d_f) = (1.00 m, 0.058m)

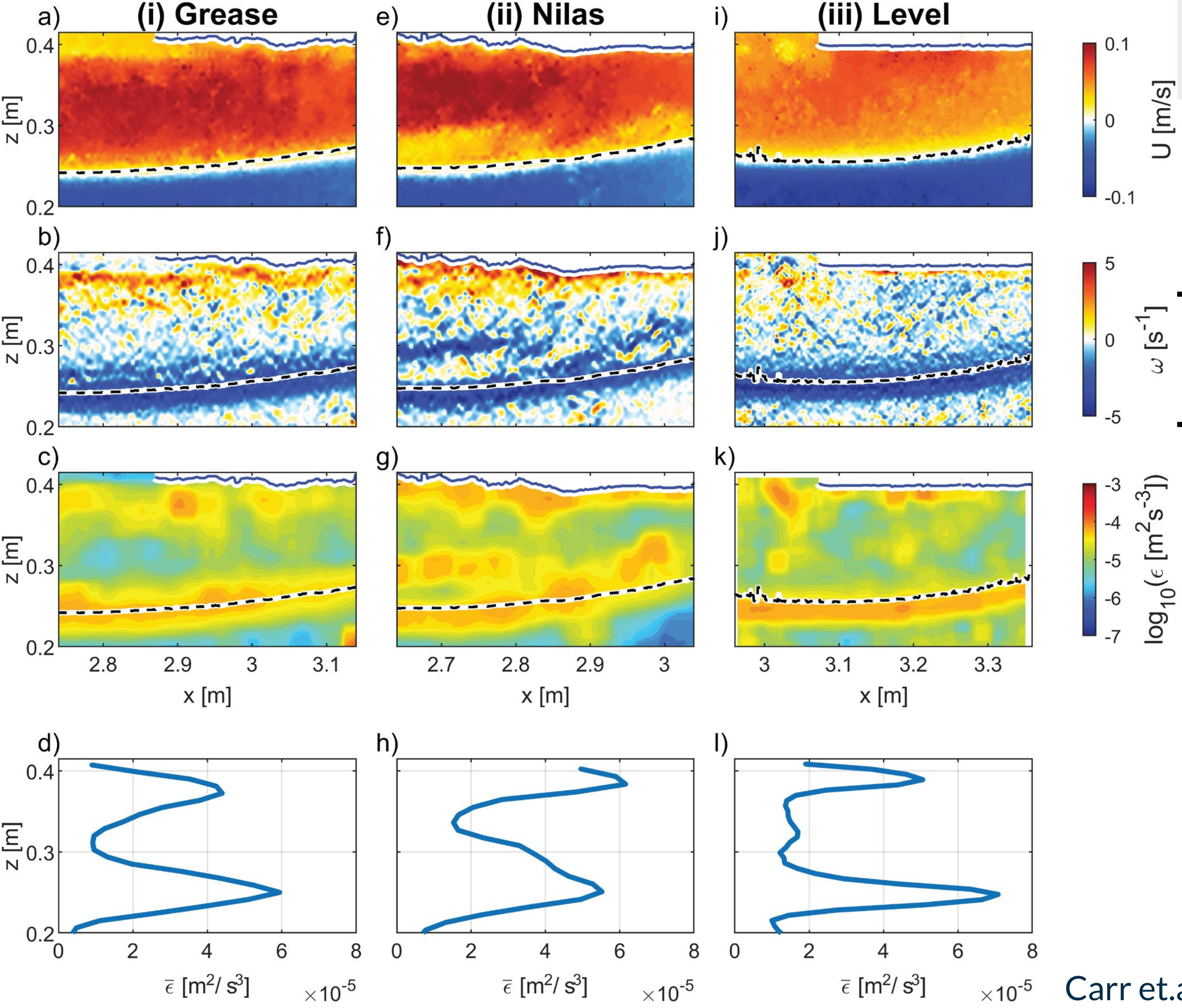
∗ Sheet ice, (l_f, d_f) = (0.95 m, 0.013m)

$$c_f/c = -0.61 l_f/2\lambda + 0.79$$

→ Longer floes move slower

? What about turbulent dissipation ?

Results - PIV



Underside of ice
Pycnocline

➔ Dissipation of TKE at underside of ice and pycnocline are comparable.

➔ TKE dissipation at underside of ice : 44% (grease) , 39% (nilas), 35% (sheet) of total dissipation.

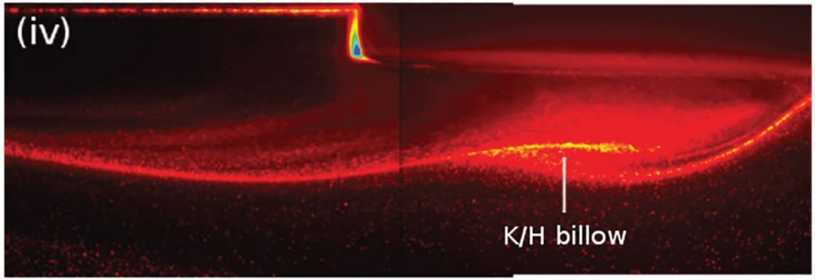
Carr et.al 2022

Conclusion (1) – Paper results & outlooks

Comparing to class

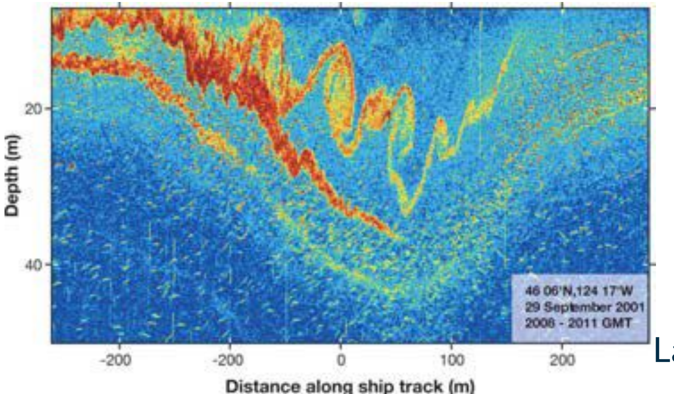
➔ 'Inverse' Dead water phenomenon

➔ Lab methods & KH



$$0.13 \leq R_i \leq 0.25$$

Carr et.al 2022



Lamb et.al 2011

Key results : Ice/ISW interactions leads to...

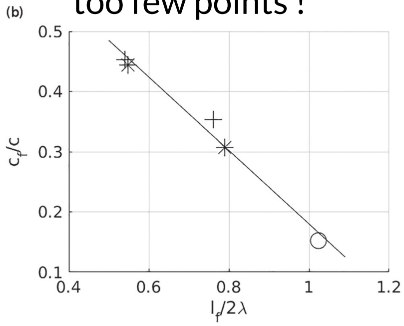
➔ ISW dissipation (friction + transport + wave deformation)

➔ Breaking and reorganisation of ice cover

Limits

	Re	N
Lab	10^3	$1\ s^{-1}$
Arctic Ocean	10^6	$0.01\ s^{-1}$

too few points !

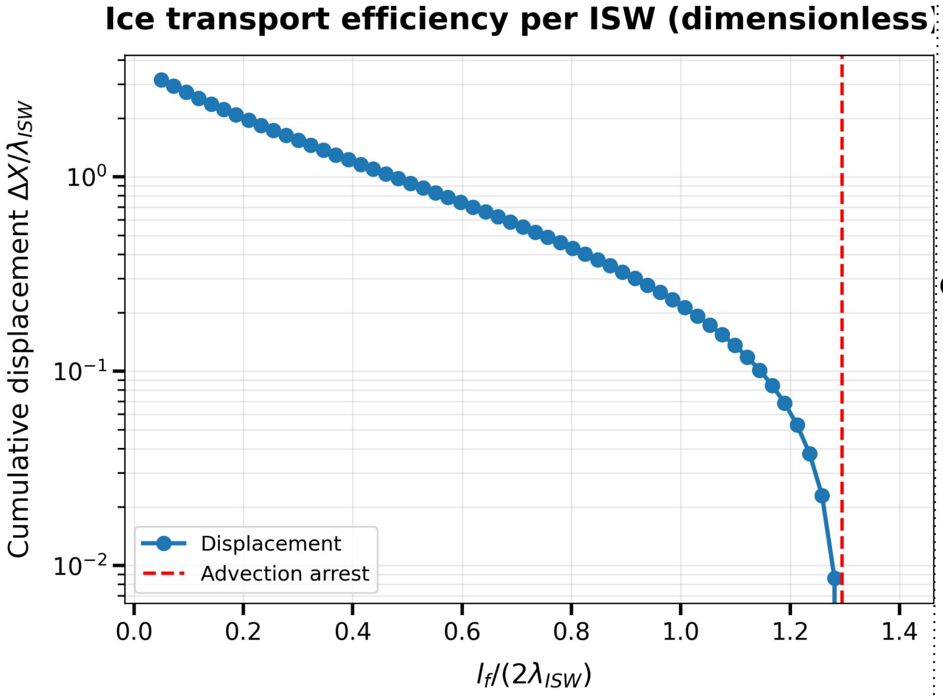


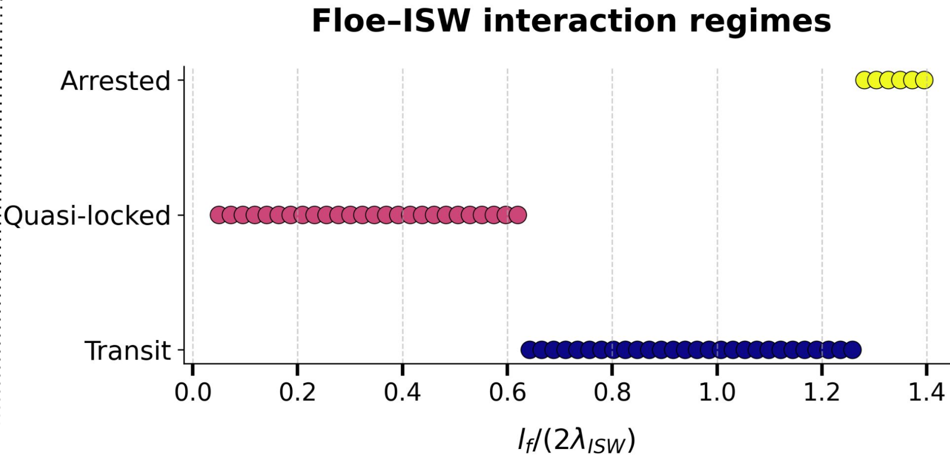
Conclusion (2) - ice transport issue

$$T_{res} \sim \frac{\lambda_{ISW}}{c_0 - c_f} \qquad \Delta X = \int_0^{T_{res}} c_f \, dt$$

$$\mathcal{L} = \frac{c_f}{c_0}$$

Regime	Criterion
Transit	$\mathcal{L} \ll 1$
Quasi-locked	$0.7 \lesssim \mathcal{L} < 1$
Arrest	$\mathcal{L} = 0$





References

Find our work and contribution here :
https://github.com/matildeb666/Internal-waves

Thanks for your attention !

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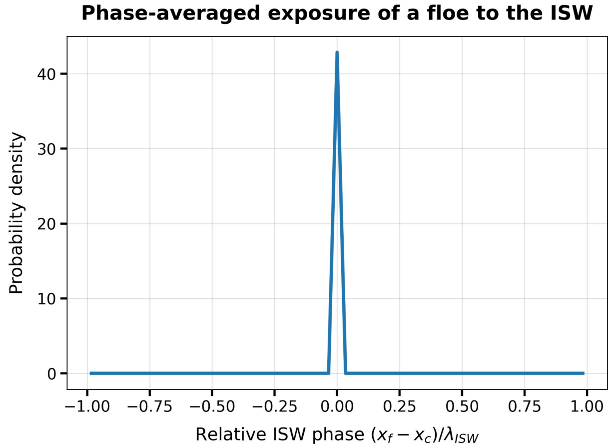
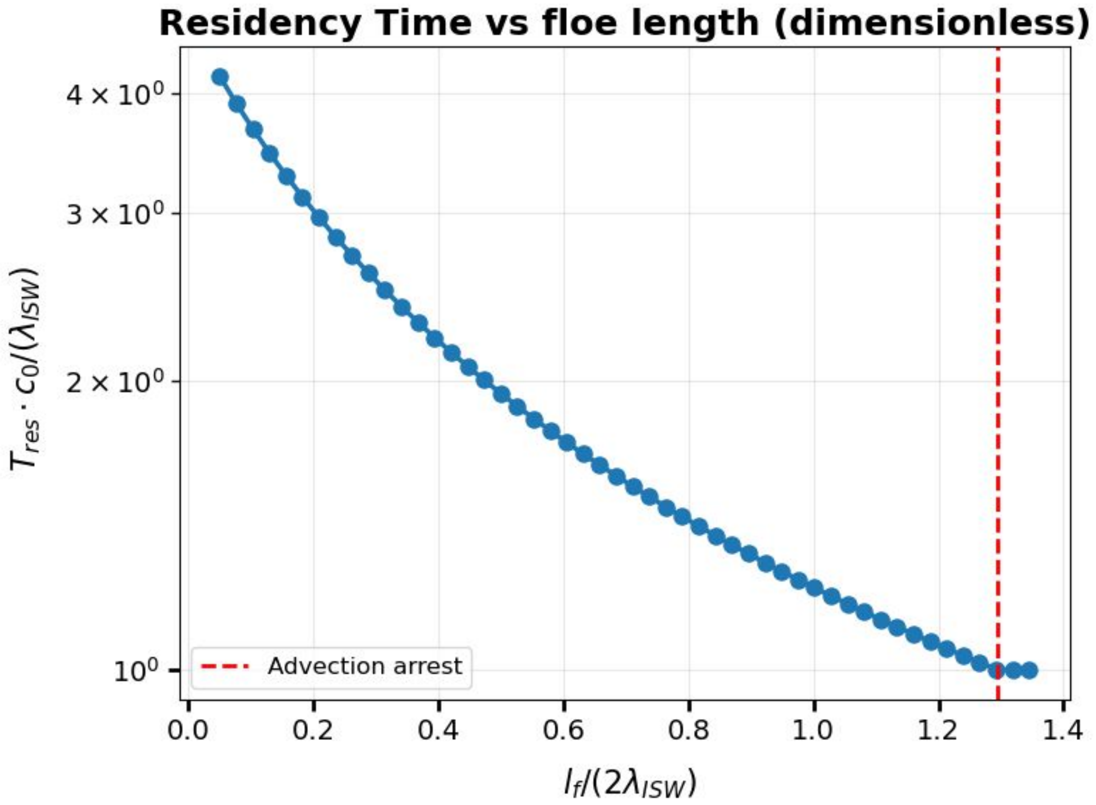
Lee waves

Conclusion (3)

$$\xi(t) = x_f(t) - c_0 t$$

$$P(\xi) = \frac{1}{T}\int_0^T \delta(\xi(t) - \xi)\,dt$$

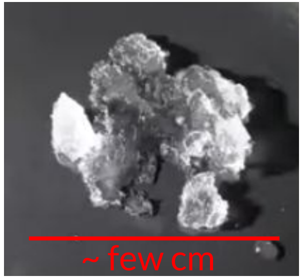




Residency Time vs floe length (dimensionless)
4×10^0
3×10^0
2×10^0
10^0
$T_{res} \cdot c_0/(\lambda_{ISW})$
Advection arrest
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
$l_f/(2\lambda_{ISW})$

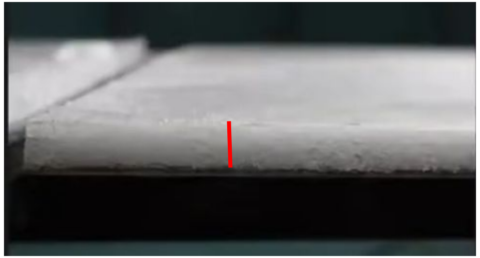
Different varieties of ice, different phenomenon

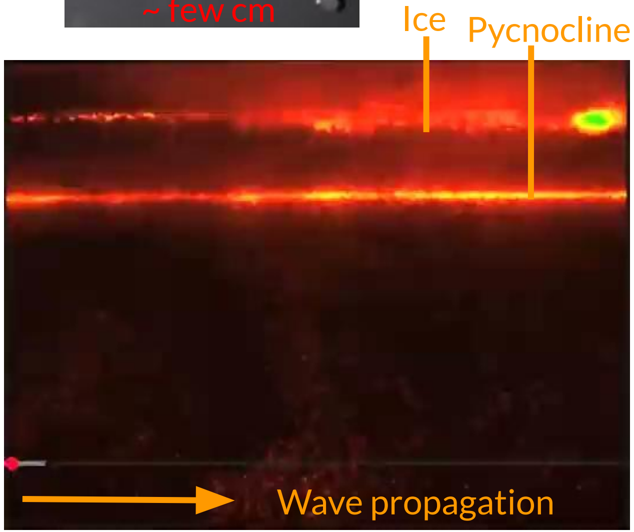
Grease ice



Nilas ice

Sheet ice





https://www.youtube.com/watch?v=yv2_hfr1wFI

? How to quantify transport/turbulent dissipation ?

Wave:Ice interaction

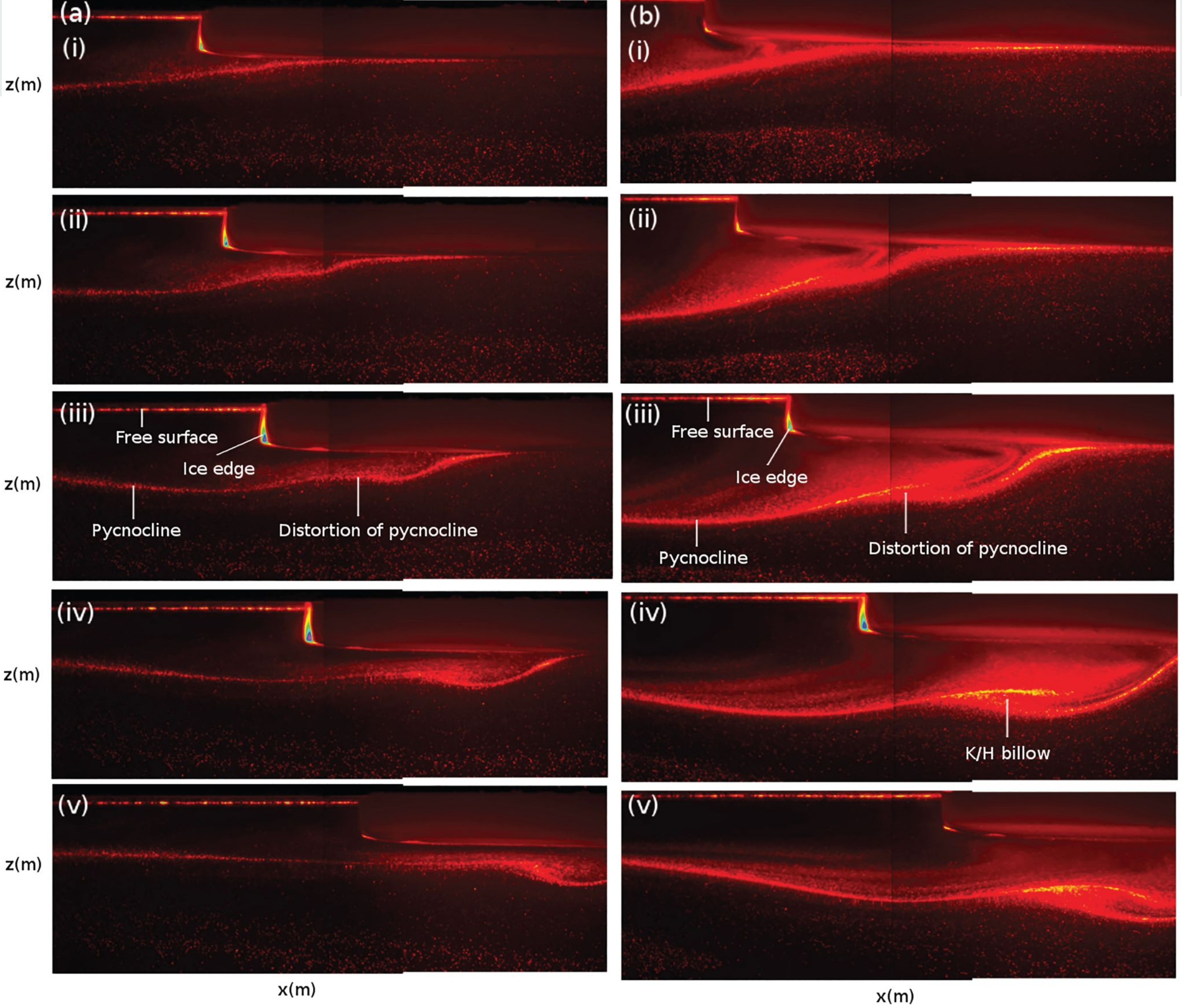
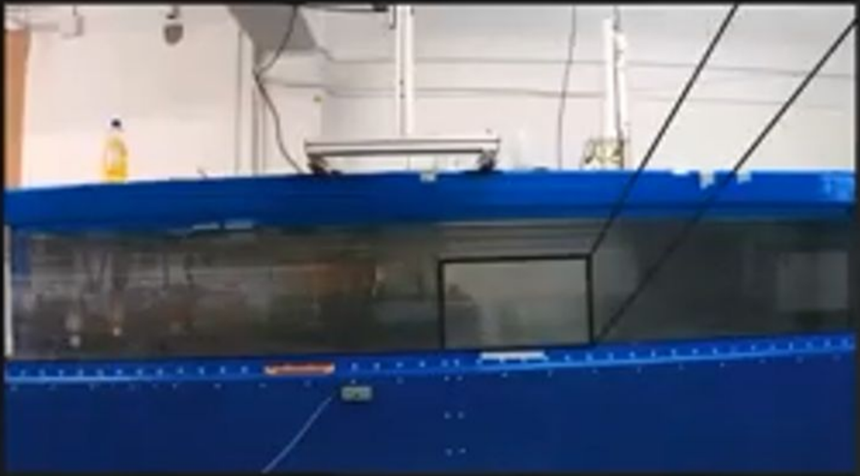
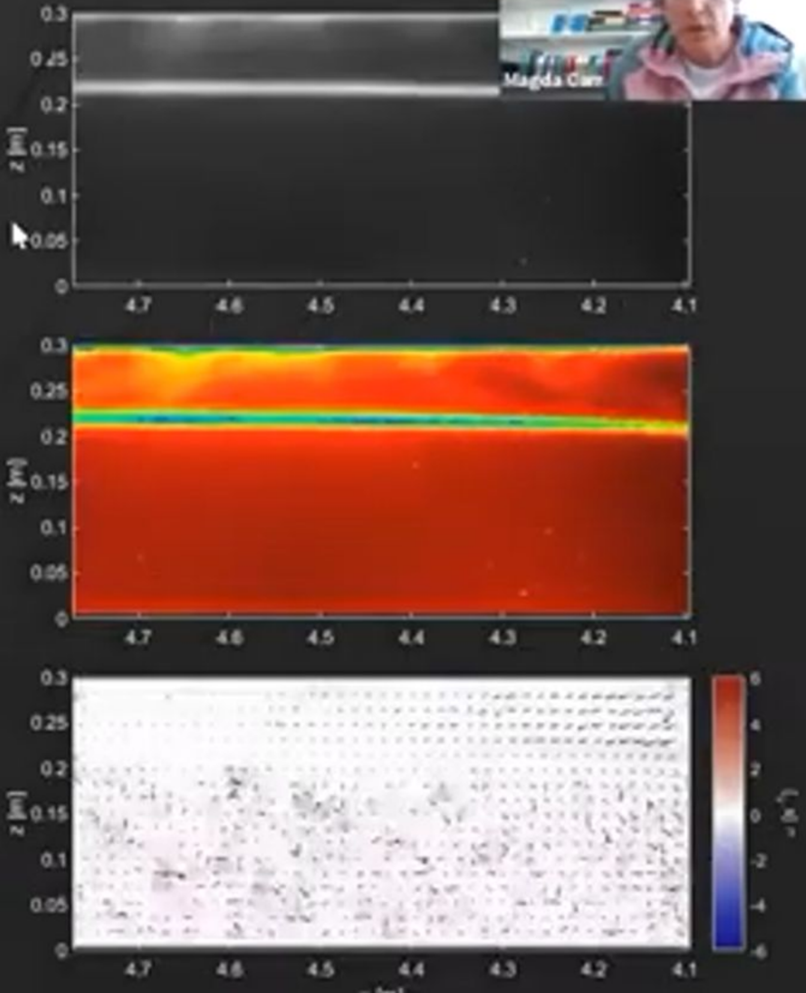


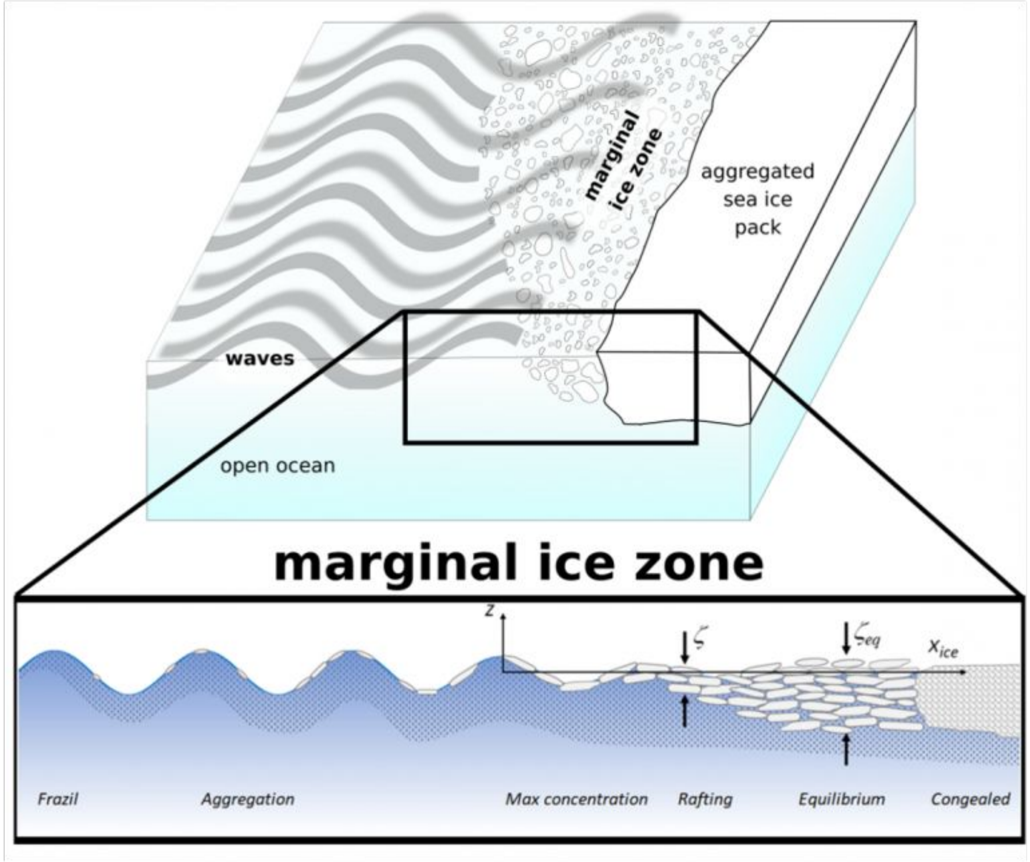
Table S1. Experimental parameters. See main article for definition of variables.

Ice Type	h_3 (m)	h_2 (m)	h_1 (m)	a (m)	c (ms^{-1})	c_f (ms^{-1})	d_f (m)	l_f (m)	c_f/c	$l_f/2\lambda$
Level	0.316	0.038	0.047	0.056	0.124	0.040	0.013	0.95	0.31	0.79
Level	0.323	0.042	0.055	0.102	0.142	0.063	0.013	0.95	0.44	0.55
Level	0.302	0.060	0.045	0.053	0.113	0.040	0.058	1.00	0.35	0.76
Level	0.314	0.059	0.053	0.113	0.138	0.063	0.058	1.00	0.45	0.54
Level	0.313	0.056	0.083	0.099	0.132	0.020	0.058	2.00	0.15	1.02
Grease	0.323	0.031	0.044	0.063	0.111	0.031	0.021	2.65	0.27	2.34
Grease	0.330	0.035	0.055	0.111	0.134	0.027	0.021	2.65	0.21	1.39
Nilas	0.321	0.035	0.044	0.048	0.116	0.000	0.006	2.69	0.00	2.01
Nilas	0.332	0.030	0.057	0.106	0.134	0.000	0.007	2.69	0.00	1.69

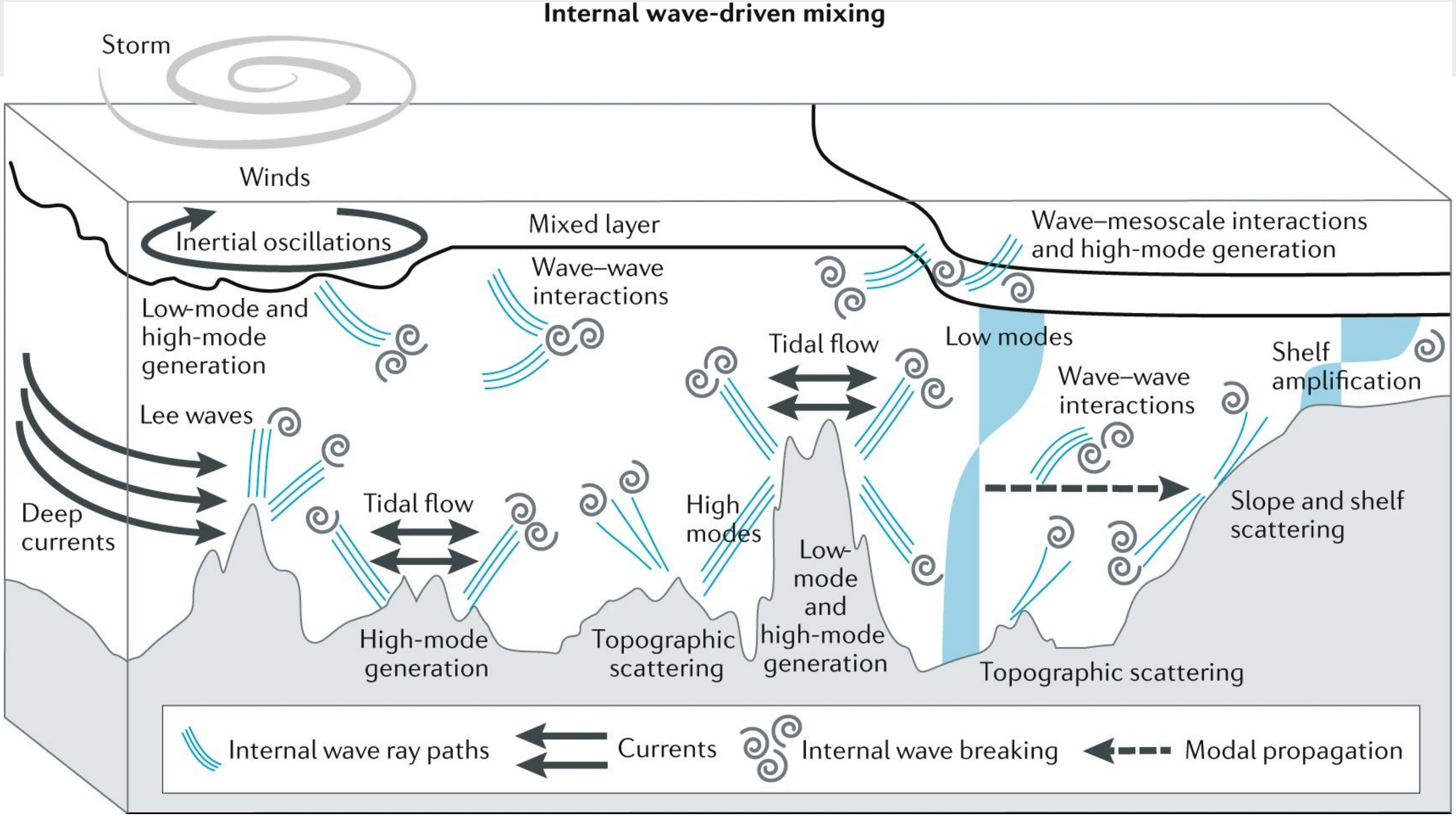
Methods







From E3SM https://e3sm.org/e3sm-next-generation-development-for-coastal-waves/Figure 2, – adapted from Dai et al. (2019) and Sutherland and Dumont (2018).



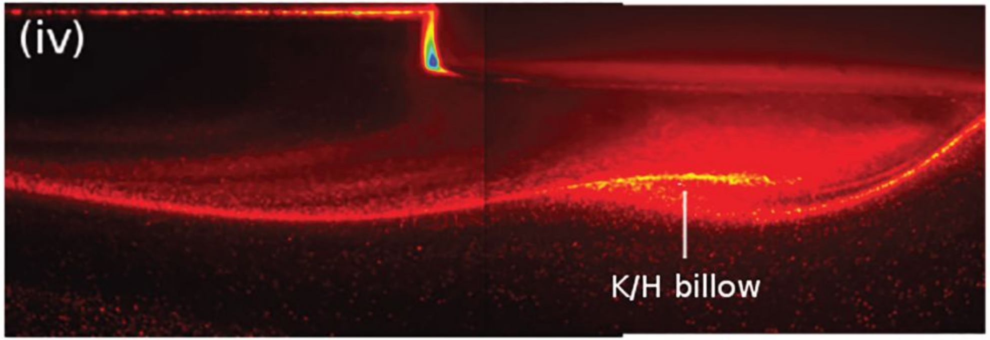
Whalen et.al, Nature 2020

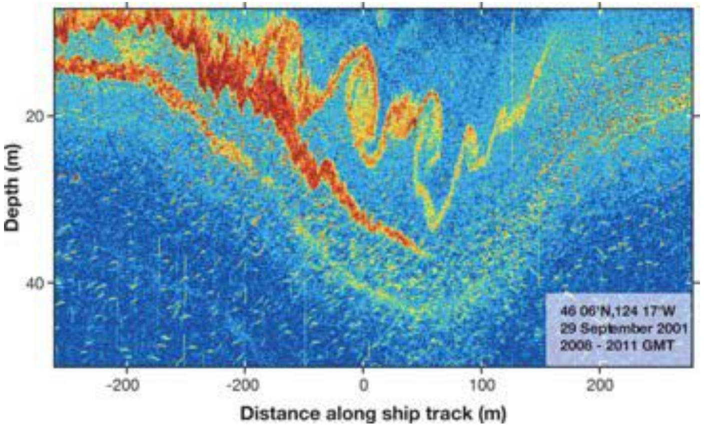
Comparing to class

Dead Water Phenomenon

➔ ‘Inverse’ Dead water phenomenon : wave induces floe motion

Lab methods





K G Lamb, D.Farmer 2011

Conclusion: criticism & outlooks

Key results : Ice/ISW interactions leads to...

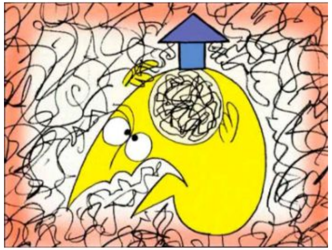
- ➔ ISW dissipation (friction + transport + wave deformation)
- ➔ Breaking and reorganisation of ice cover

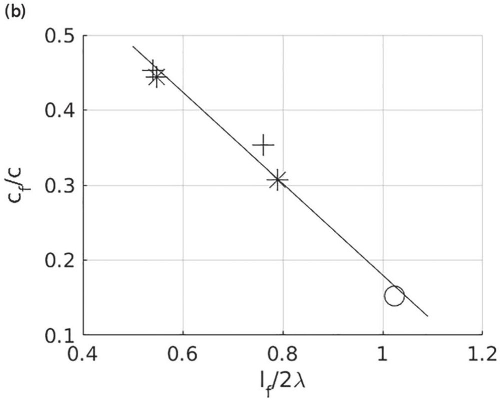
Further work and outlooks

- ➔ Fake floes and ice motion with collisions
- ➔ Numerical collisions

Limits

	Re	$N = \sqrt{\frac{-g}{\rho_0}\frac{\partial \rho}{\partial z}}$
Lab	10^3	$1\ s^{-1}$
Arctic Ocean	10^6	$0.01\ s^{-1}$





too few points !