Wave groups and spectral shape in ice

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Enhanced group structure of waves in ice - Linear or nonlinear process?

Motivation:
Previous case study in pancake ice (Thomson et al 2019, JGR):

High frequency wave attenuation
→ narrow band
Linear superposition
→ Strong group structure

Here: new study, 4 year record, including thick first year ice

Definitions: Wave parameters

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Significant wave height $H_s = 4\sqrt{m_0}$

Spectral moments

$$m_n = \int \omega^n S(\omega) d\omega$$

Dominant frequency $\omega_p = \frac{\int \omega S(\omega)^4 d\omega}{\int S(\omega)^4 d\omega}$

Spectral bandwidth $\nu = \left(\frac{m_0 m_2}{m_1^2} - 1\right)^{\frac{1}{2}}$

Steepness $\varepsilon = k_p H_s / 2$

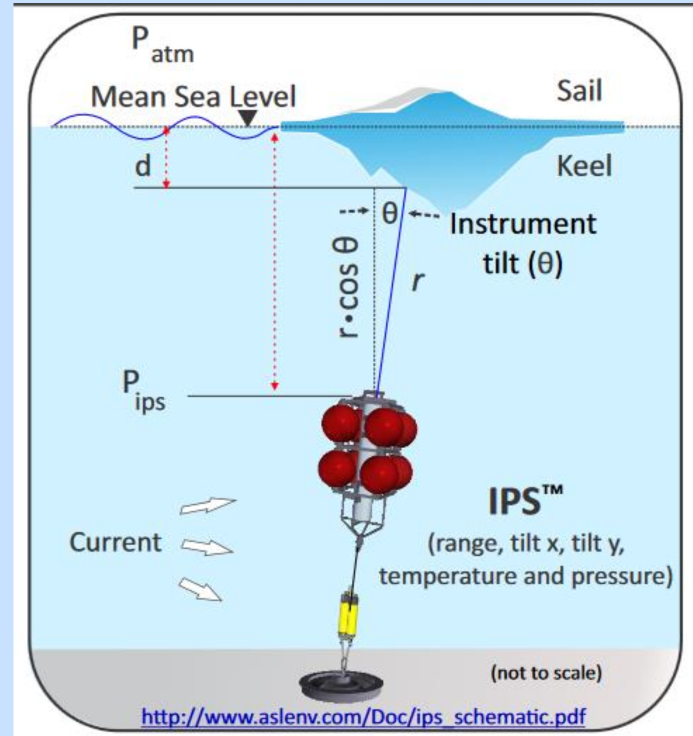
Group factor

$$GF = \frac{\sigma_{SWH}}{\langle SWH \rangle}$$

Smoothed Instantaneous **W**ave Energy **H**istory (wave envelope) $SWH = Q * \eta^2$

(Q: Bartlett window length $2T_p$)

Observations: surface elevation (various ice conditions)



Observations 2010 – 2015

2 sites: Burger and Crackerjack, ~47m depth

- Range to surface at 0.5 Hz (some 1 Hz),

→ 1d 'surface elevation' time series
(inverted echosounder range)

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Group factor – wave steepness

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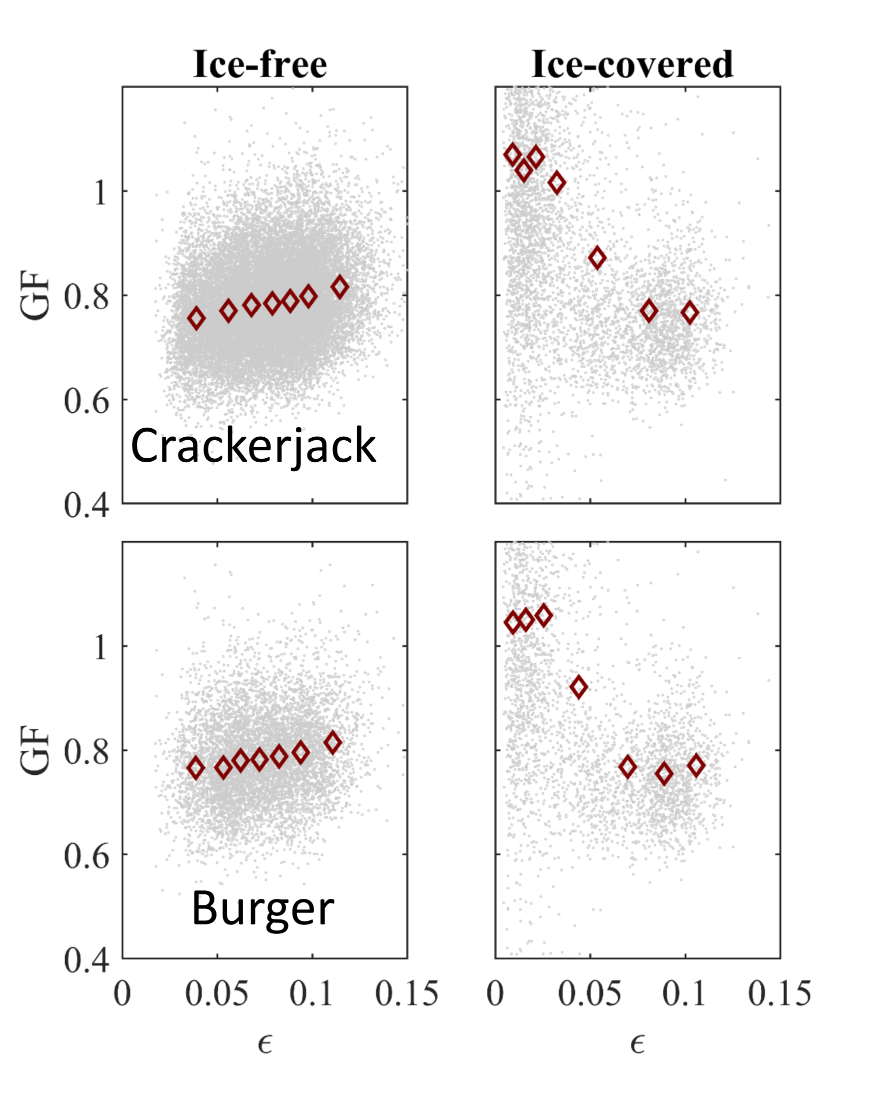

Ice free:

- Lower GF
- **Steeper waves**
  → more pronounced groups

Ice covered:

- Higher GF
- **Steeper waves**
  → less pronounced groups

Similar steepness in ice and ice-free
(despite lower Hs)
→ Attenuation of longer waves (?)
Or change in dispersion relation (?)

(Note: in pancake ice: GF highest in ice, decreasing with steepness)

Group factor – bandwidth

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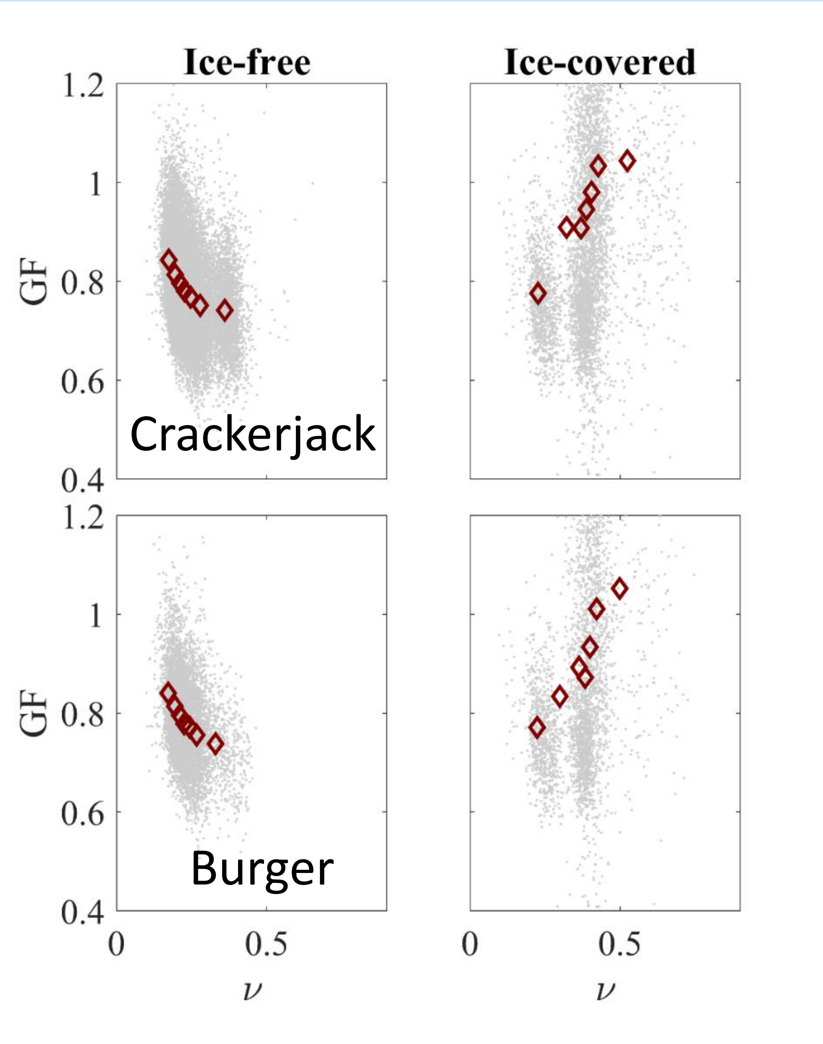

Ice free:

- **Narrow-banded waves**
  → more pronounced groups

Ice covered:

- **Broad-banded waves**
  → more pronounced groups

Similar bandwidth in ice or ice-free

→ Why?
(would expect high-frequency attenuation in ice
→ linear: narrow band)

(Note: in pancake ice: GF highest in ice, decreasing with bandwidth)

Group factor – bandwidth: nonlinear process

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Original Russian Text © V.G. Polnikov, I.V. Lavrenov, 2007, published in Okeanologiya, 2007, Vol. 47, No. 3, pp. 363–373.

MARINE PHYSICS

Calculation of the Nonlinear Energy Transfer through the Wave Spectrum at the Sea Surface Covered with Broken Ice

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Note: Spectral bandwidth defined omni-directional, but group generation effective in unidirectional waves

Ice reduces nonlinear 4-wave transfer
but enhanced transfer to high frequencies
(compensates for high frequency attenuation: → $n_{ice} \sim n_{water}$)
→ High frequency spreads to lateral directions
→ Waves in dominant direction more "narrow-banded"
→ Increase in group factor

Process less pronounced in narrow band wave field

Broad-banded waves → high frequency lateral spread → more pronounced groups

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Summary

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Wave groups in ice: linear or nonlinear?

Thin ice: Group factor decreasing with bandwidth **linear** [a]

Thick ice: Group factor increasing with bandwidth **nonlinear** [b]

Ice enhances nonlinear 4-wave transfer to high frequencies
→ Lateral spread → more groups in dominant direction

Spectral parameter ← → groupiness:

Opposite behaviour in thick ice vs. open water

[a] Thomson et al, 2019

[b] This study. Consistent with nonlinear mechanism suggested in Collins et al, 2015

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References:

Collins, C.O., W.E. Rogers, A. Marchenko, and A. V. Babanin, 2015: *'In situ measurements of an energetic wave event in the Arctic marginal ice zone'.* Geophys. Res. Lett.,42, 1863–1870

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