Effects of waves on ice shelves

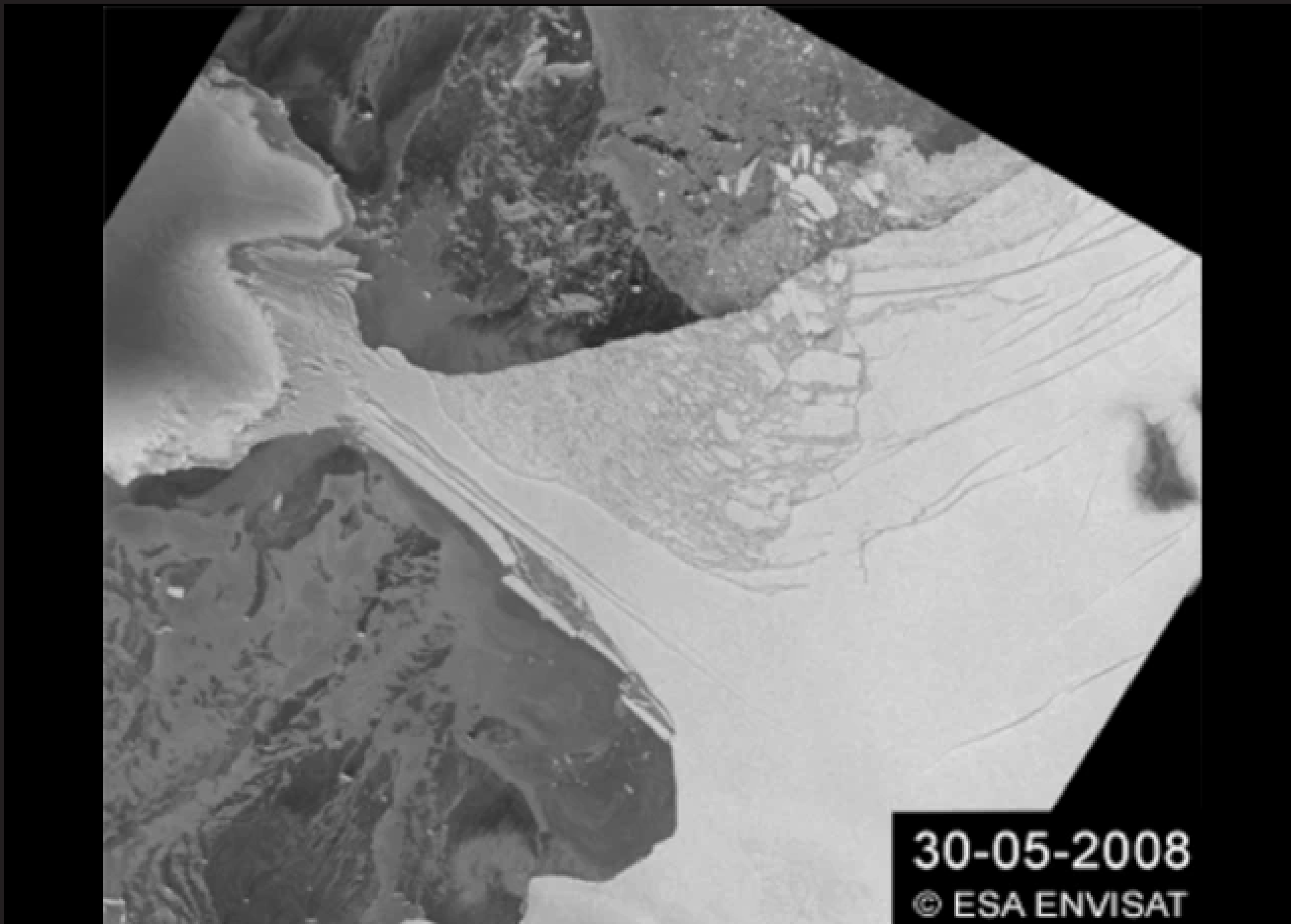
The other form of ice-shelf ocean interaction

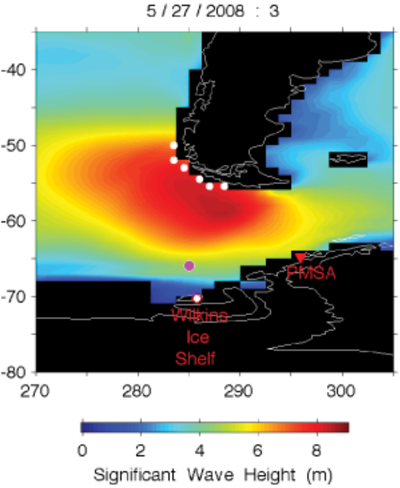
Olga Sergienko

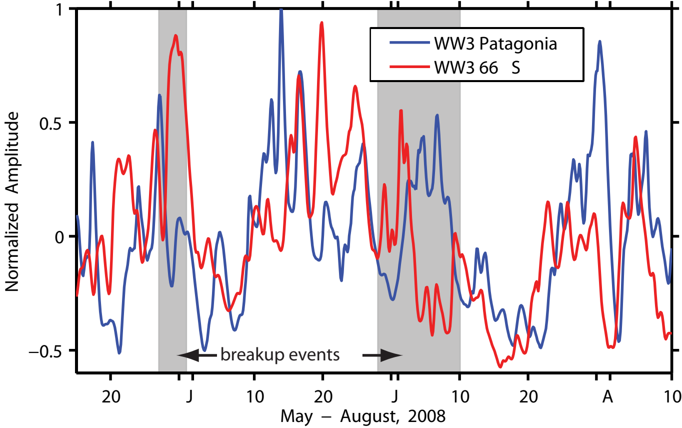
with inspiration from

Peter Bromirski and Doug MacAyeal

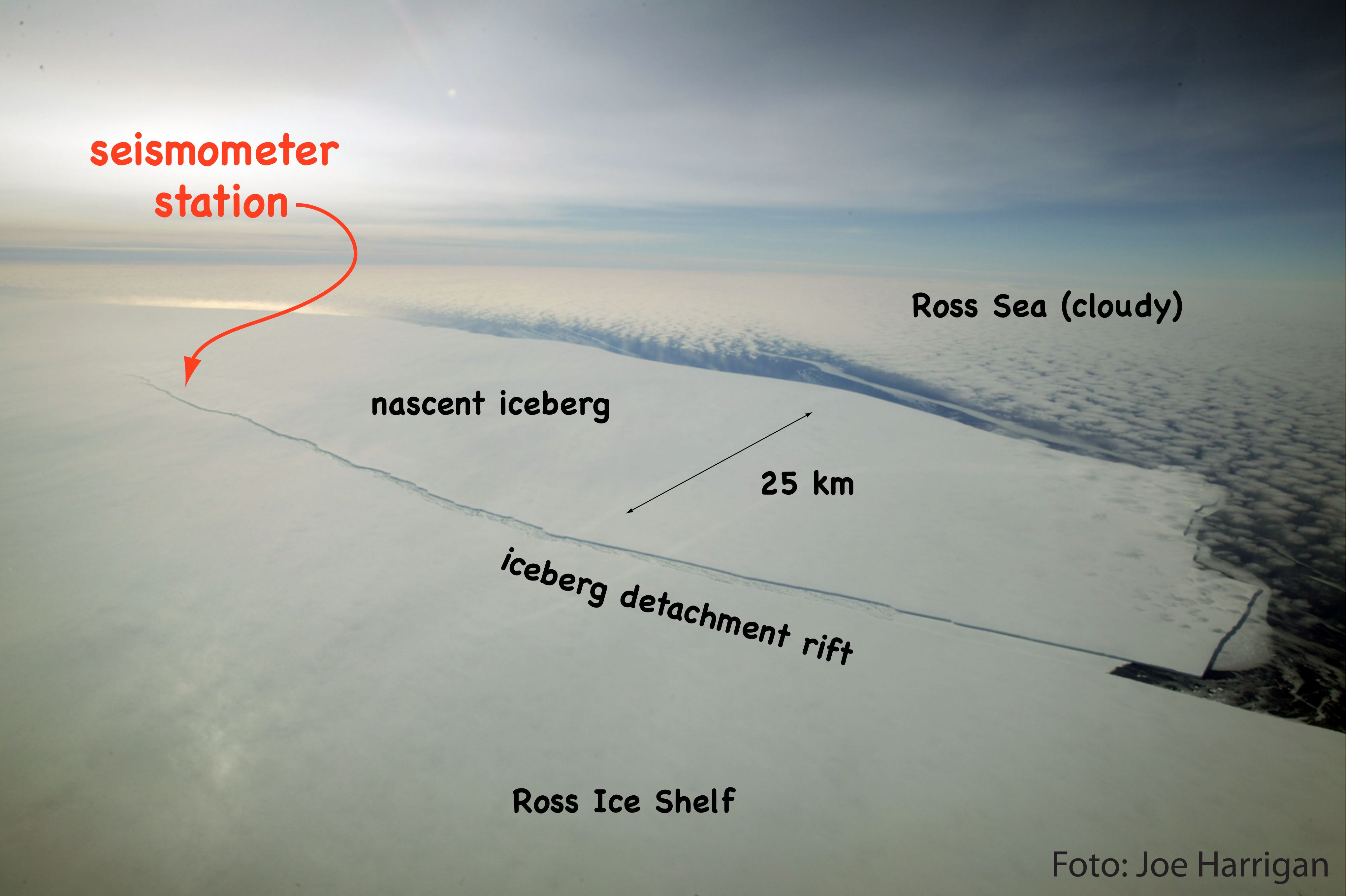
Wilkins winter break up







WaveWatch III™


seismometer station
Ross Sea (cloudy)
nascent iceberg
25 km
iceberg detachment rift
Ross Ice Shelf
Foto: Joe Harrigan

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L17502, doi:10.1029/2006GL027235, 2006

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Transoceanic wave propagation links iceberg calving margins of Antarctica with storms in tropics and Northern Hemisphere

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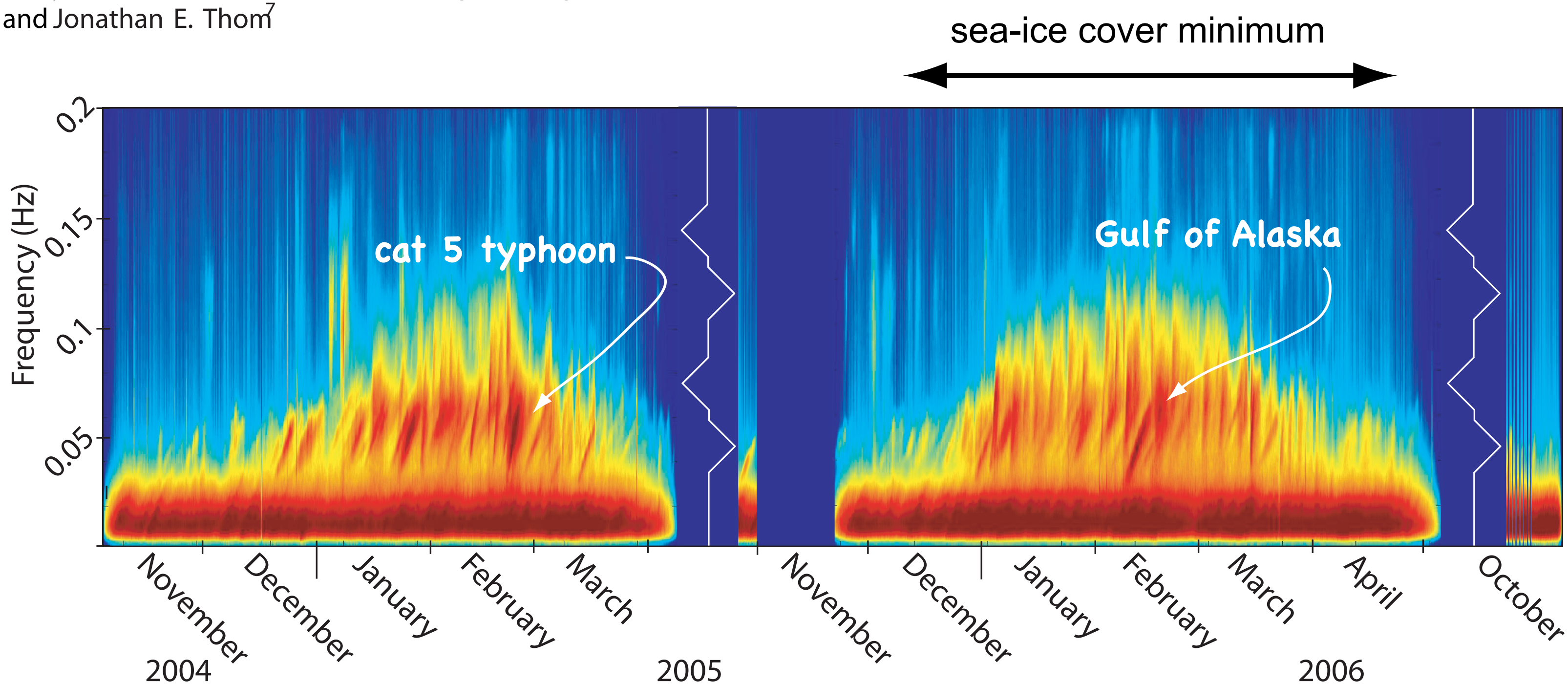
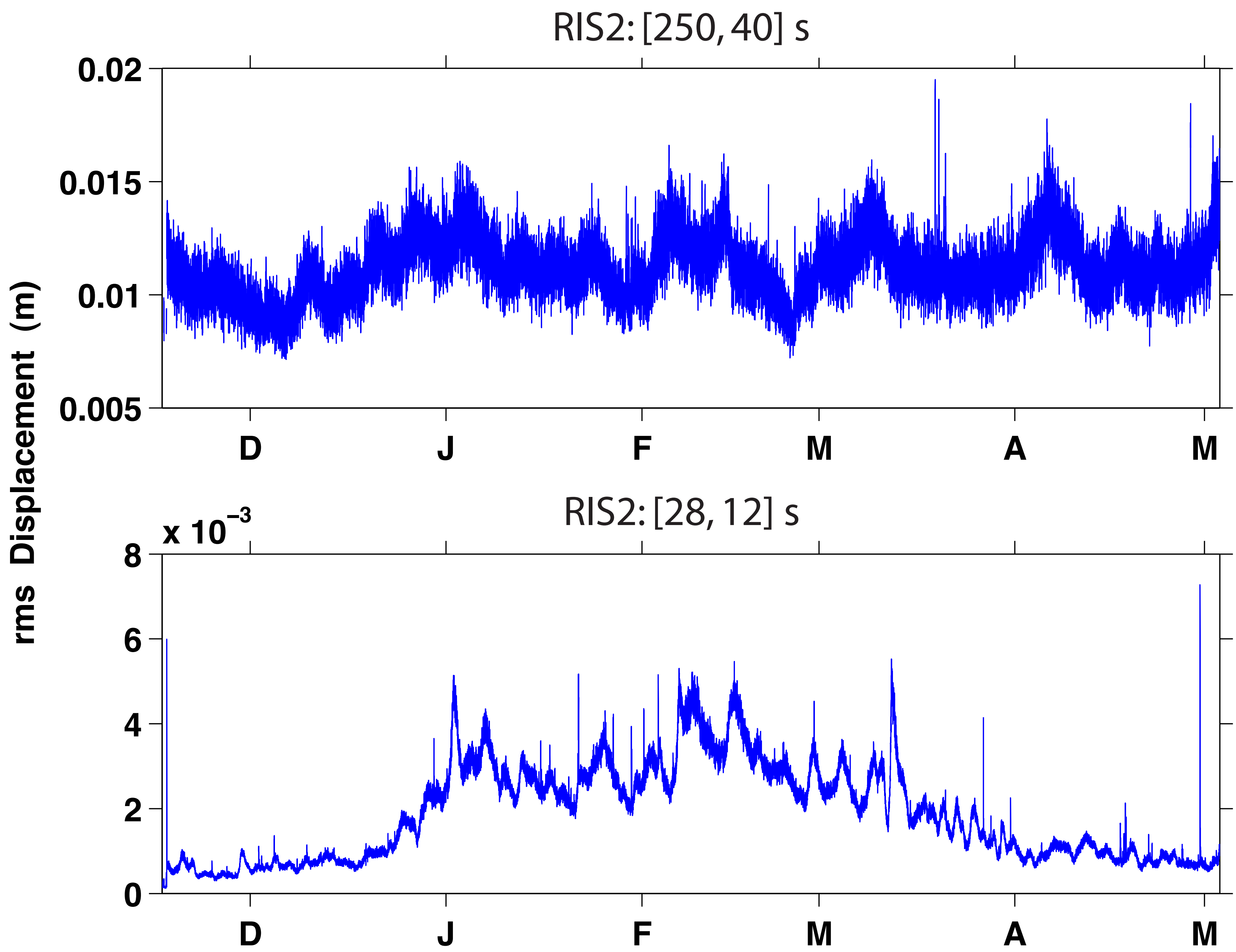
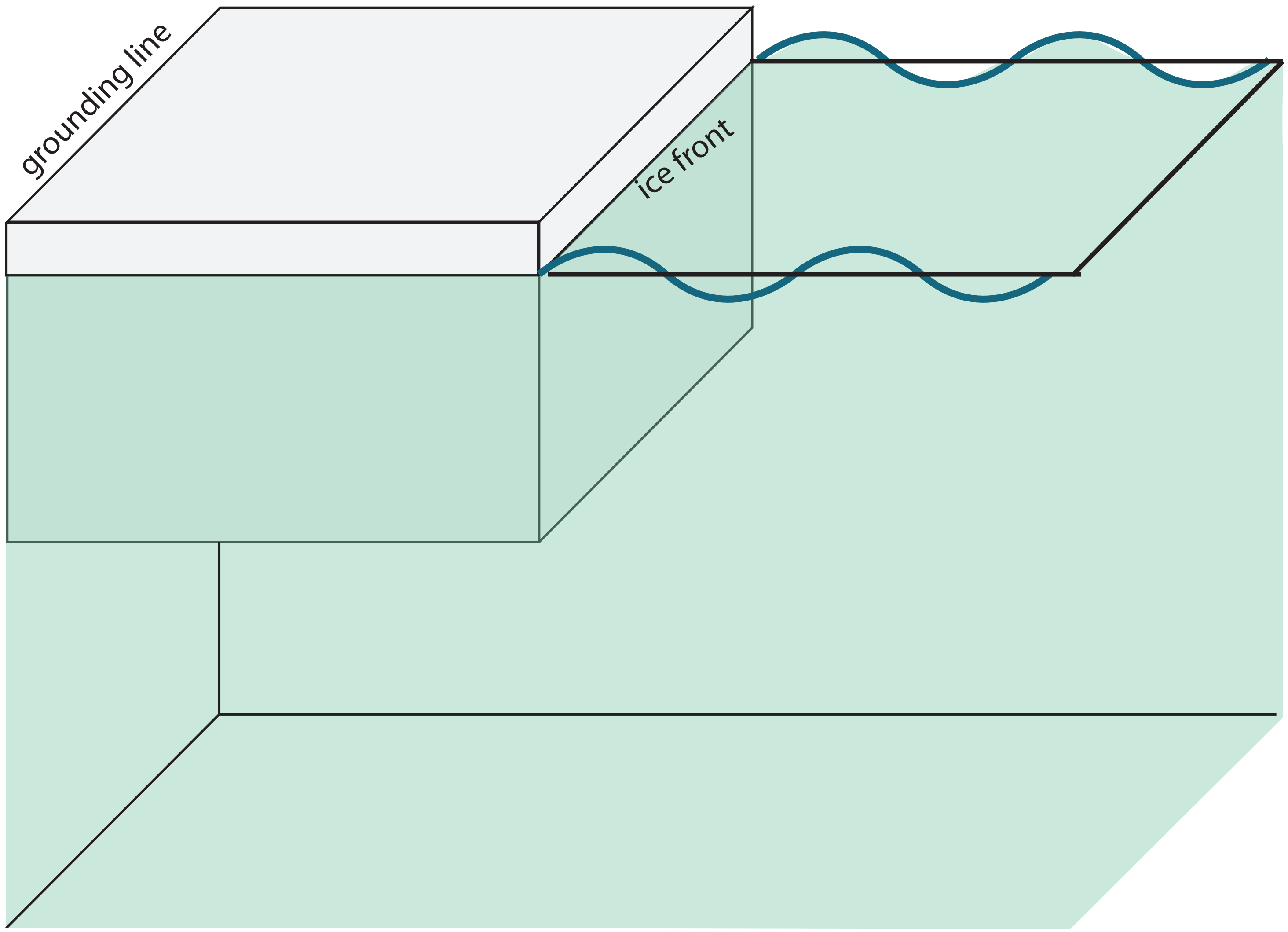


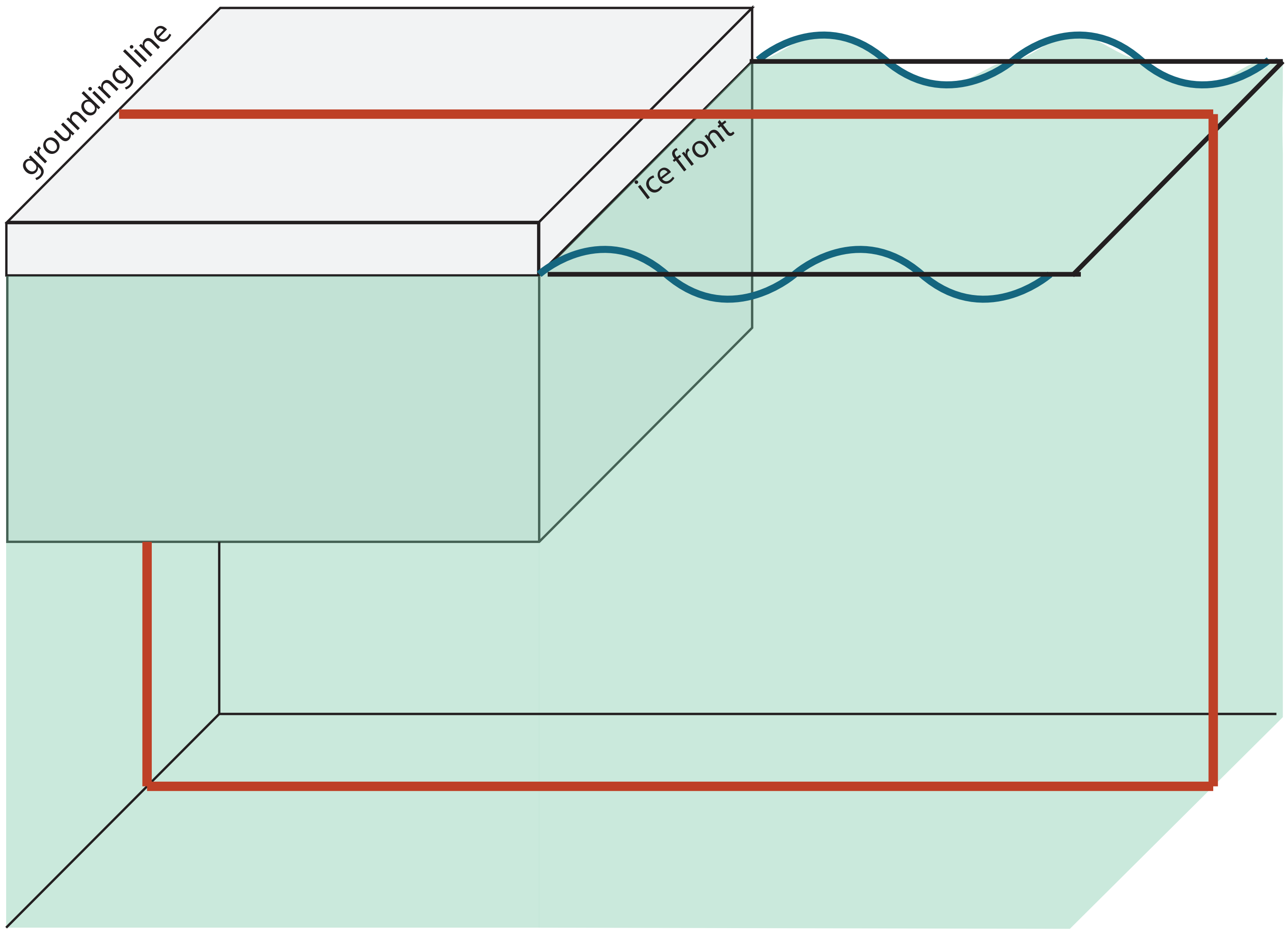
Seismogram from Nascent Iceberg



courtesy of P. Bromirski (Scripps)

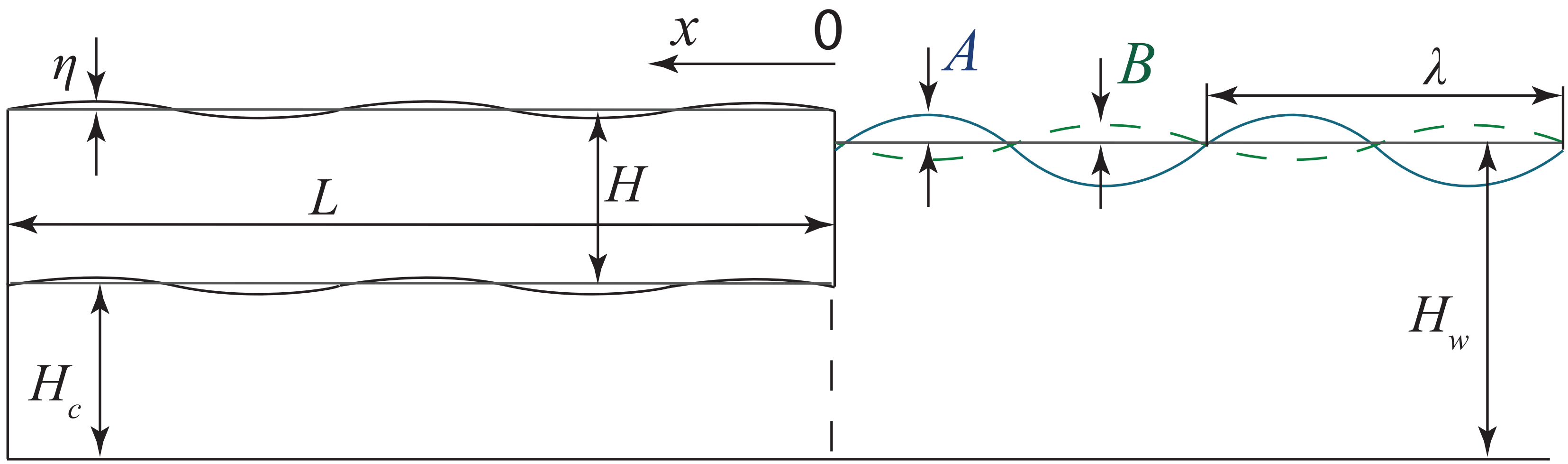


1. Ice is elastic → Hook’s law
2. Water is irrotational and inviscid → potential flow


grounding line
ice front

Long wave approximation

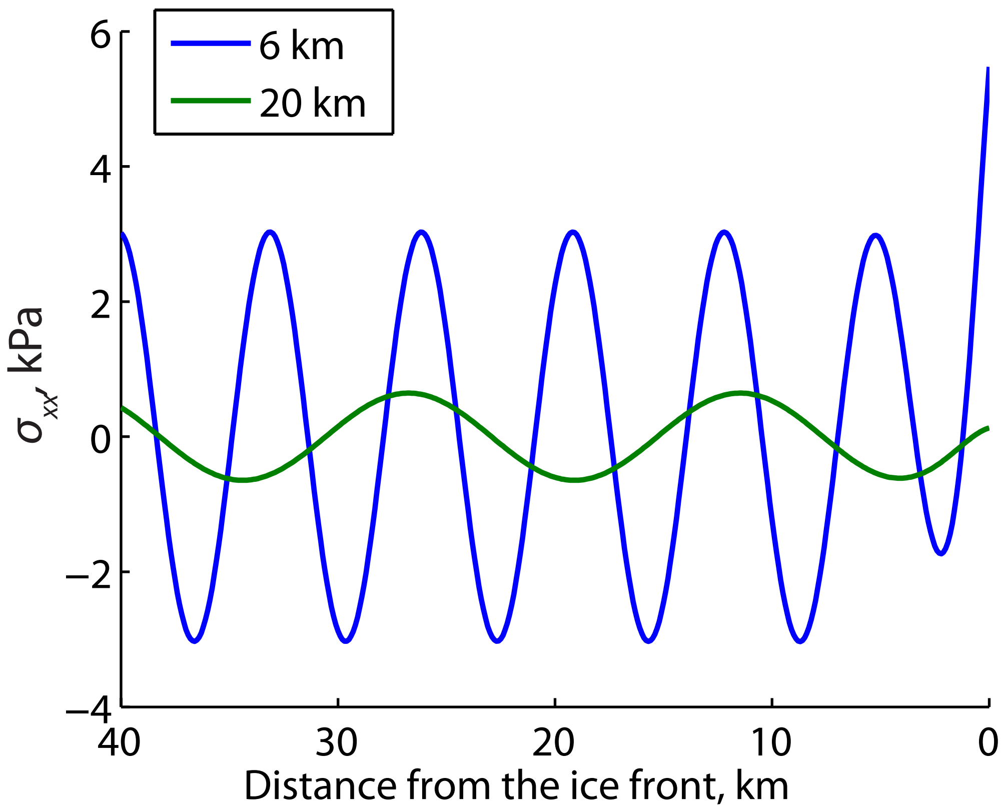
$$\lambda = T\sqrt{gH_w} >> H_w$$



$$\sigma'_{xx} = \frac{1}{2} E H \eta_{xx}$$

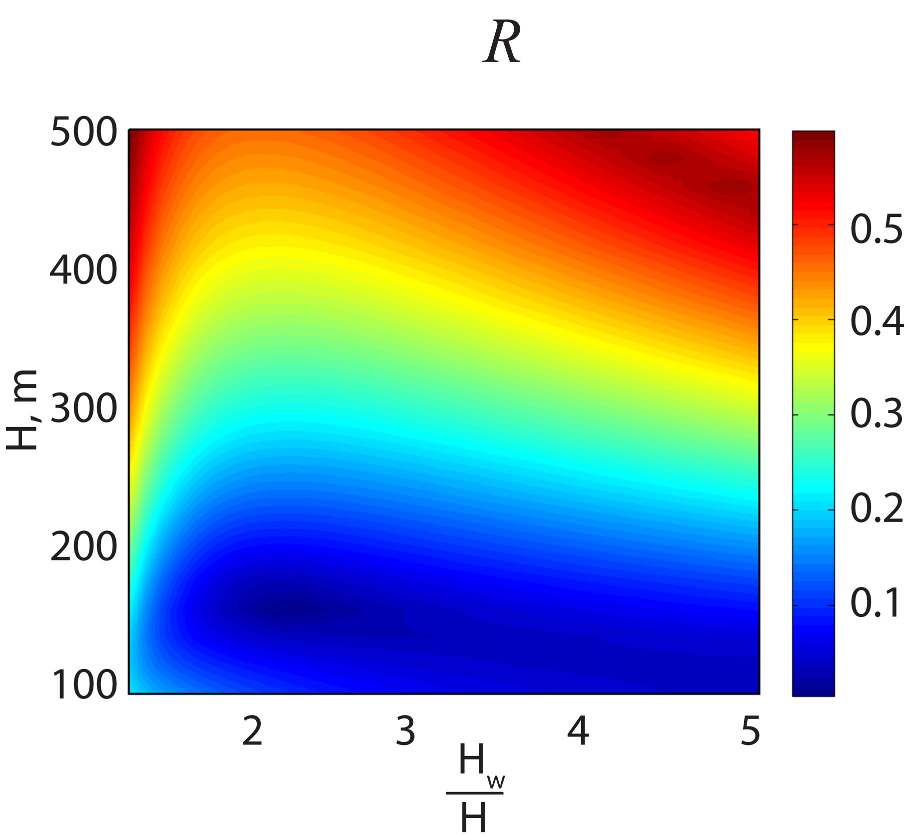
$$R = \frac{B}{A}$$

Wave-induced stress

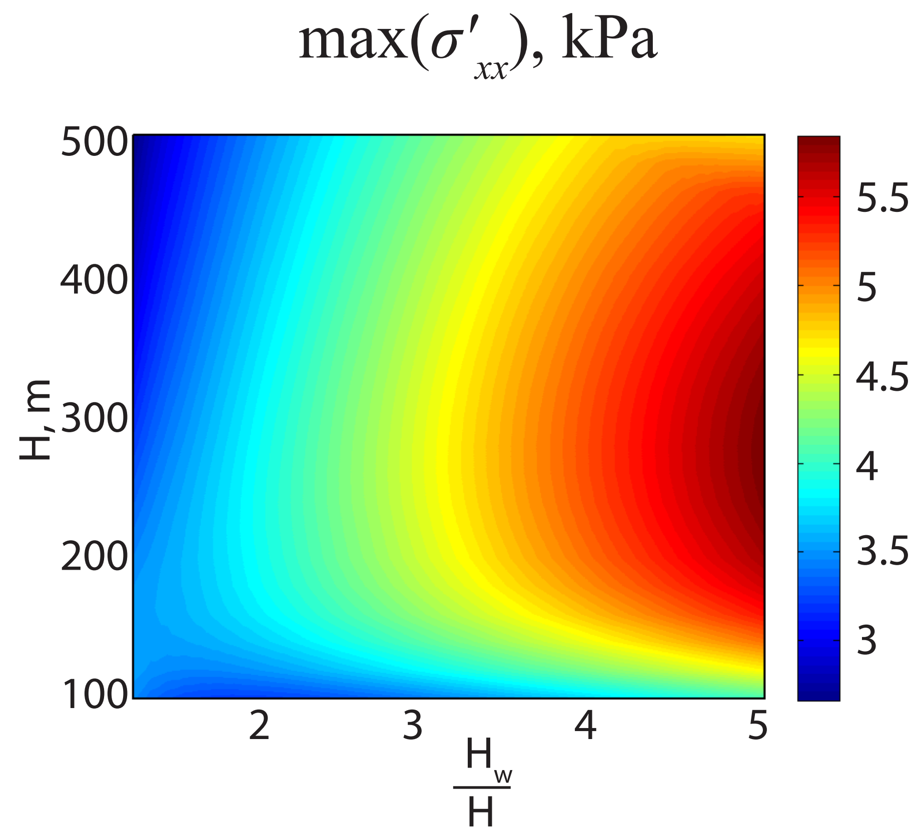


H = 300 m, H_w = 600 m

6 km wave



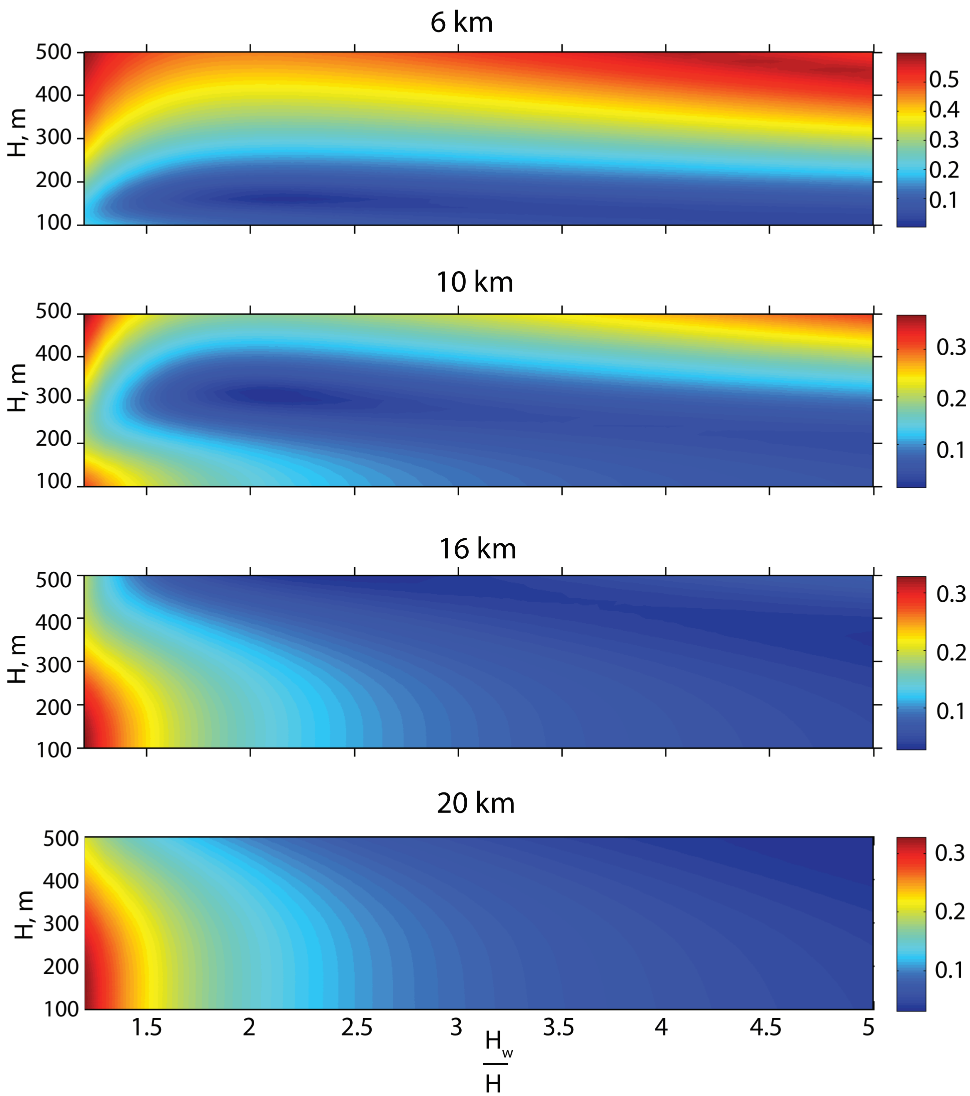
R
500
400
300
200
100
H, m
2
3
4
5
$\frac{H_w}{H}$
0.5
0.4
0.3
0.2
0.1



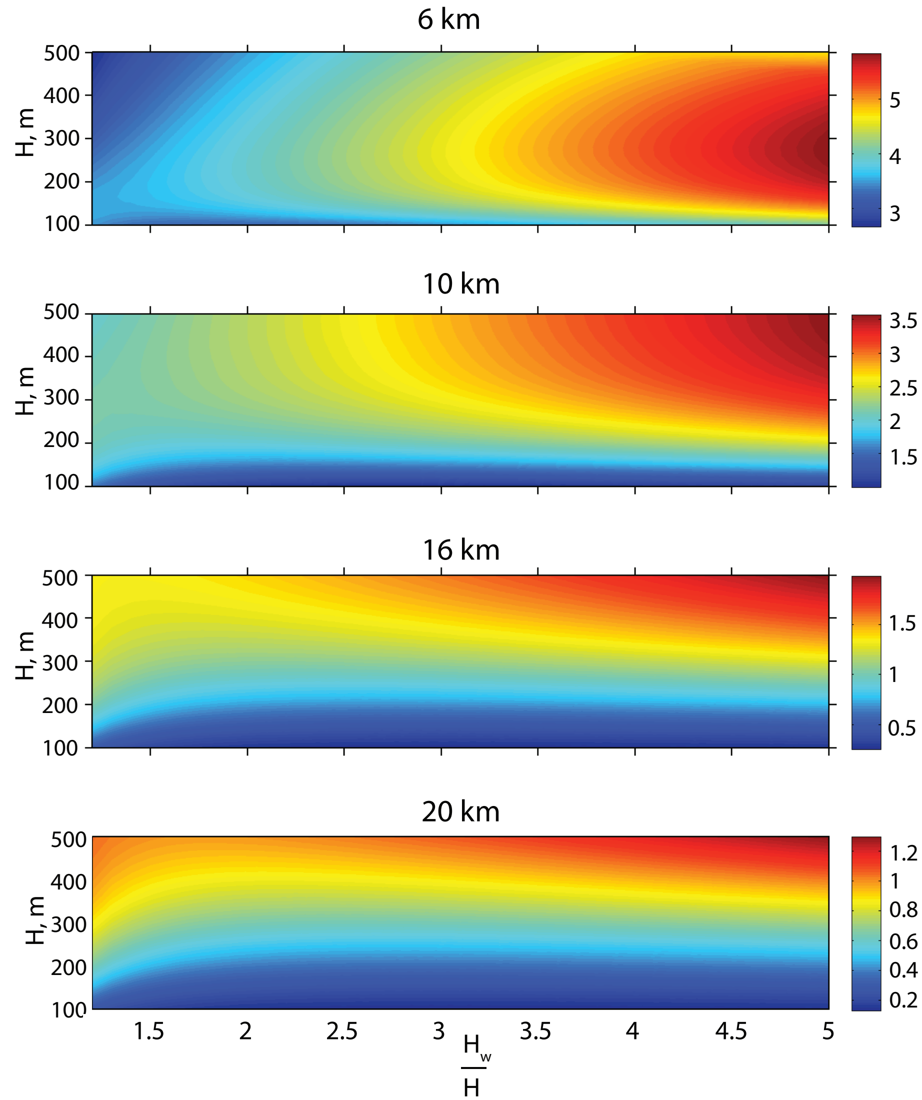
$\max(\sigma'_{xx})$, kPa
500
400
300
200
100
H, m
2
3
4
5
$\frac{H_w}{H}$
5.5
5
4.5
4
3.5
3

Effects of waves with various lengths

R

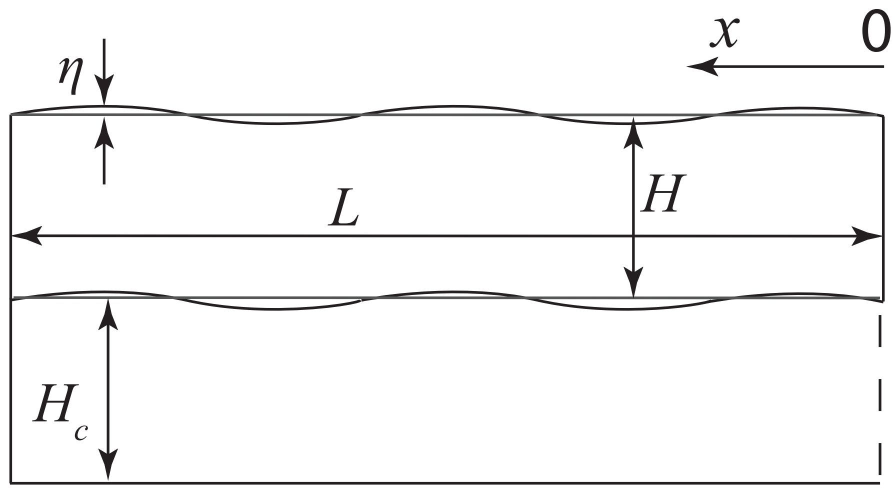


$\max(\sigma'_{xx})$, kPa



Normal modes

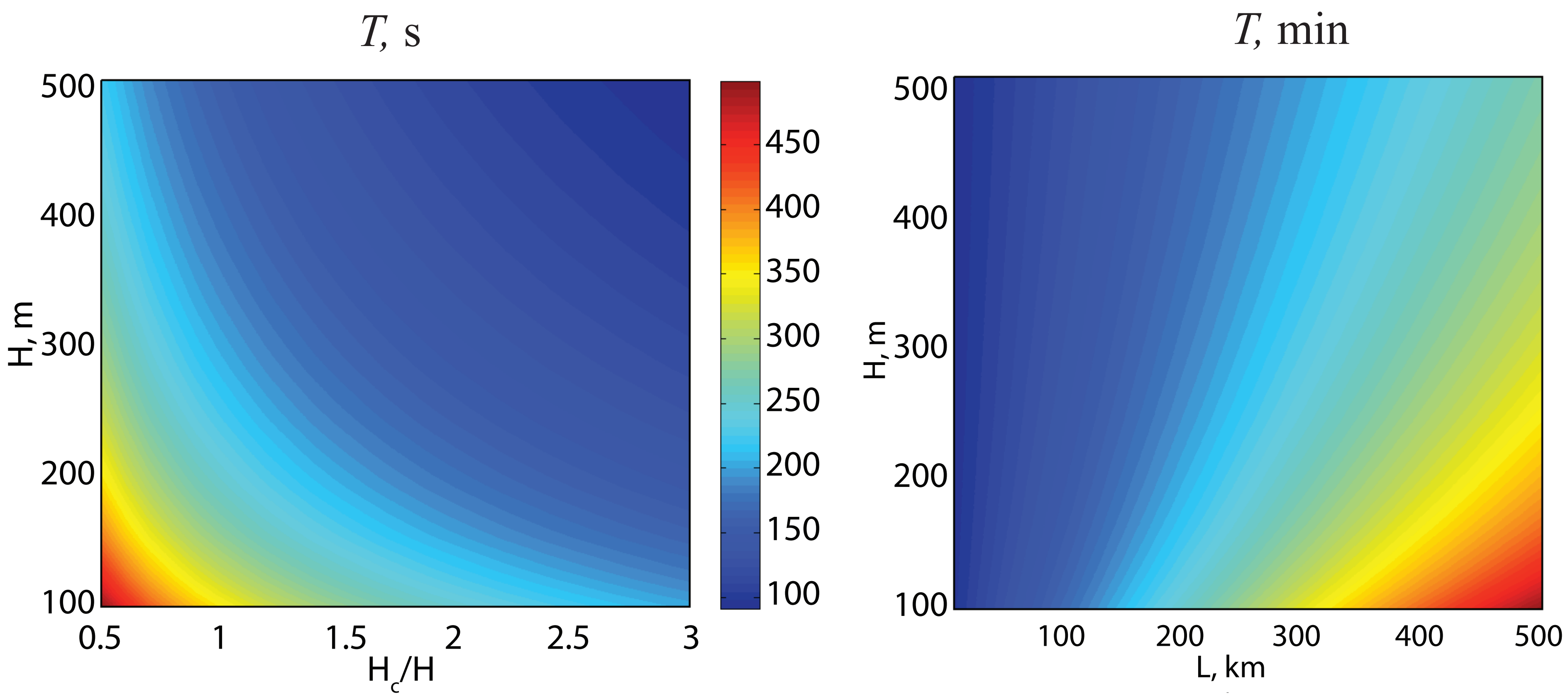
free oscillations



$$\omega_n^2 = \kappa_n^2 H_c \frac{D\kappa_n^4 + \rho_w g}{\kappa_n^4 \rho_i H_c H + \rho_w}$$

$$\kappa_n \approx \frac{\pi}{L}\left(n + \frac{1}{6}\right)$$

Periods of normal mods



$L = 50$ km

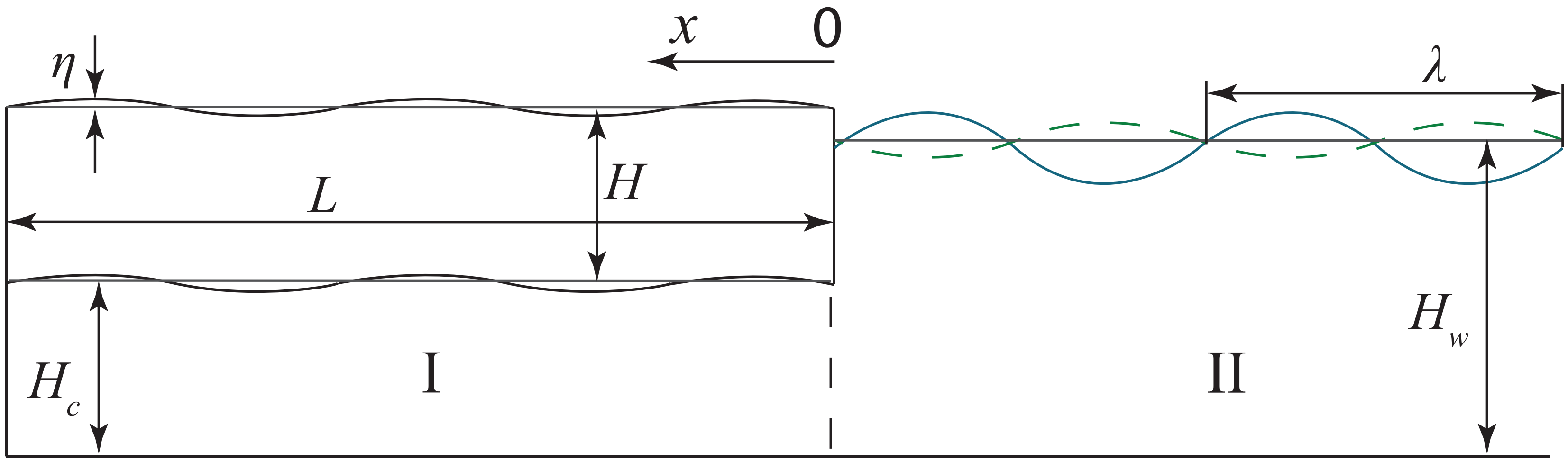
$\frac{H_c}{H} = 1$

Summary

- Wave-induced stresses are **additional** to all other stresses
- Wave impacts are cyclic and superimposable
- Implications
  — might trigger ice-shelf collapse
  — might control calving

Long wave approximation

$$\lambda >> H_w$$



I

$$\eta_t + H_c \Phi_{xx} = 0$$

$$\rho_i H \eta_{tt} = -D\eta_x^{IV} - \rho_w \Phi_t - \rho_w g \eta$$

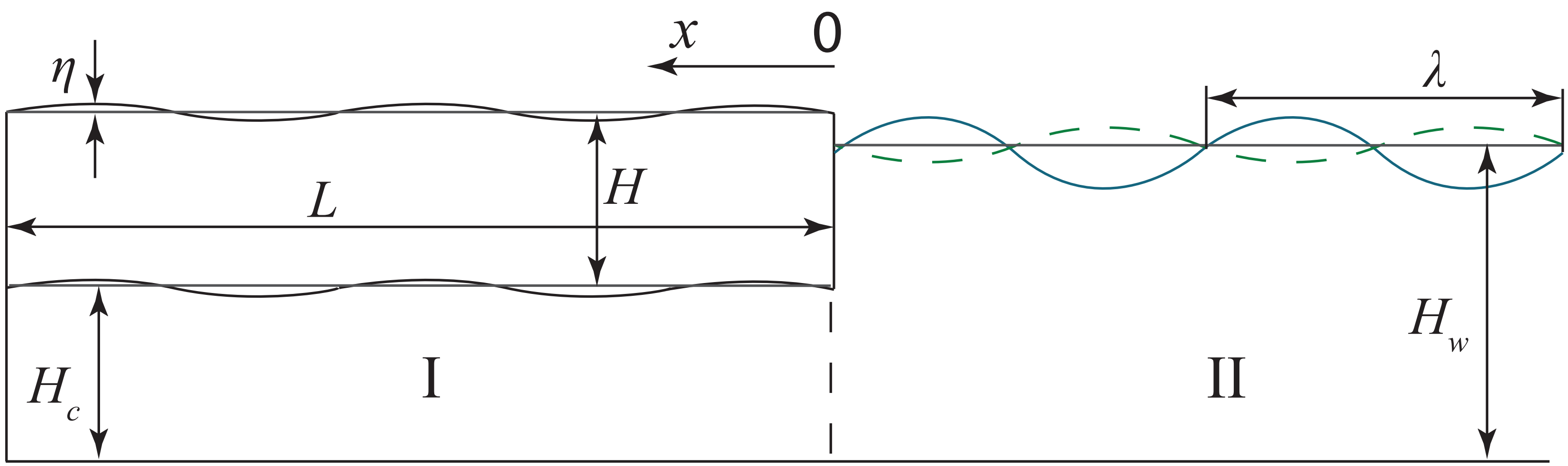
$$D = \frac{E\,H^3}{12(1-\nu^2)}$$

II

$$\Phi_{tt} + gH_w \Phi_{xx} = 0$$

Long wave approximation

$\lambda >> H_w$



I

$$\Phi = e^{i\omega t} \sum \varphi e^{i \varkappa x}$$

$$\eta = e^{i\omega t} \sum \varsigma e^{i \varkappa x}$$

$$H_c \varkappa^2 (D\varkappa^4 + \rho_w g - \omega^2 \rho_i H) + \omega^2 \rho_w = 0$$

II

$$\Phi = A e^{i(\omega t + kx)} + B e^{i(\omega t - kx)}$$

$$\omega = k\sqrt{g H_w}$$

Steady-state deviatoric stresses