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Measuring floating ice thickness with optical fibers and DAS, a test case study on a frozen mountain lake

O. Coutant, *Nziengui D., Moreau L., Boué P., Larose E., Cimolino A.* *@ ISTerre-UGA*

Two experiments were conducted during winter 2020 and 2021 on a 400m long frozen lake (elev. 2000m) using two different settings:

2020: **fiber buried in snow** / **2021**: **fiber installed on early ice with a drone**

Objectives:

- test the feasibility of seismic recording on floating ice using DAS and optical fiber
- Seismic recording of trapped waves in the ice guide allows to measure fundamental parameters of the ice layer
    - E: young modulus + H ⇔ resistance and thickness
- Implication for the ice pack and frozen lake/fjord characterization (environmental and safety issues)

Wavefield in a Floating ice layer (Stein et al. 1998)

Free ice layer ⟺ Stress free plate

Waves: Lamb waves (**A_n, S_n**) + Shear-Horizontal (**SH_n**)

Floating ice layer ⟺ floating plate

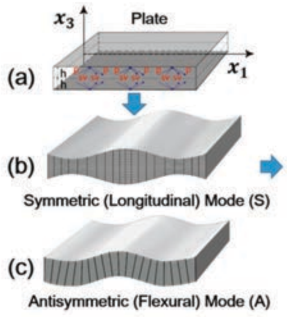
* Additional waves ~ Scholte wave (interface solid-liquid)
* Modification of the dispersion branches of guided modes
* Waves: **QA_n, QS_n ,QS** (Q=« Quasi ») + **SH_n**

<u>We record below the cutoff frequency of higher modes</u>

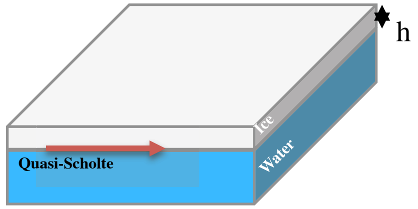
For freq x thickness < 50 Hz.m :

A_0 = leaky mode
QS = Sholte / flexural
QS_0 = axial / longitudinal
SH cannot be catched by the fiber

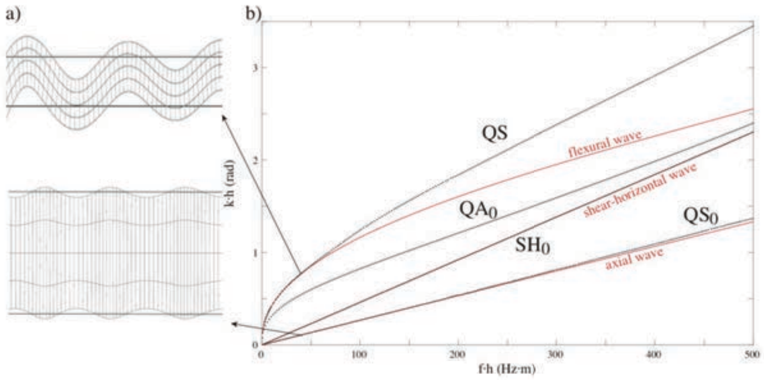
<u>Lamb waves</u>



<u>Floating ice layer</u>



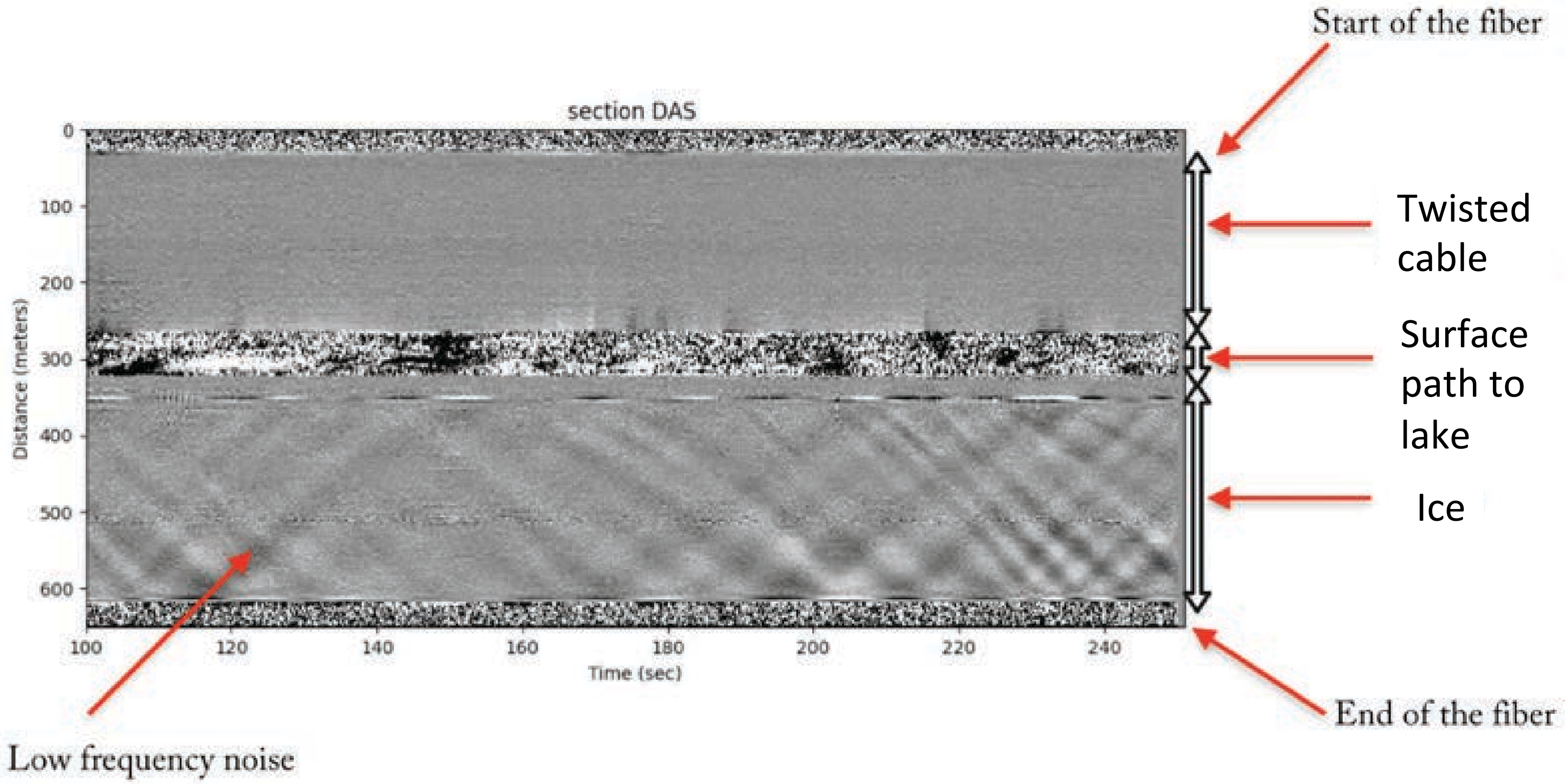
<u>Dispersion curves of the ice layer</u>



Two experiments during winter 2020 and 2012 at Lacs Roberts

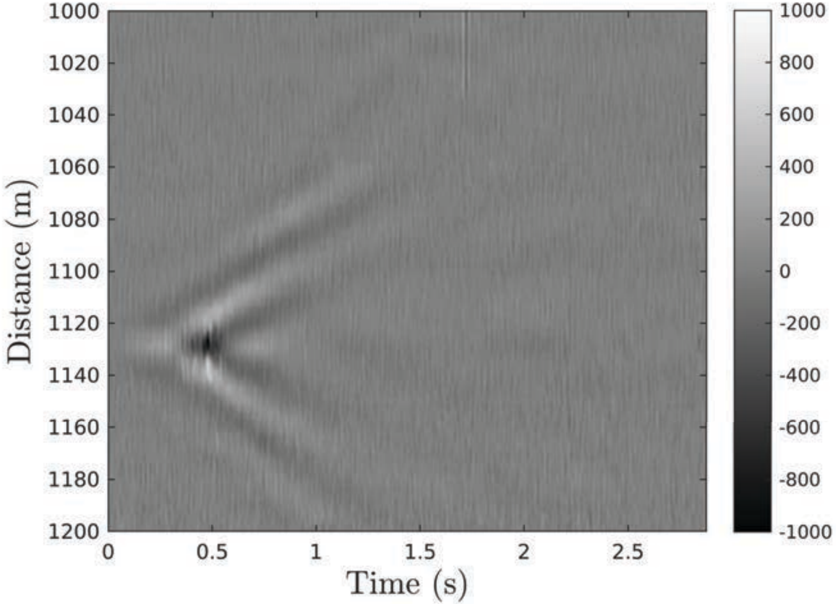
	2020	2021
Active fiber length	200m	320m
Optical parameters	PRF =2000 Hz dx=0.8m SR : GL=10m DT=2ms	PRF =2000 Hz dx=0.1m SR: GL=2m DT=5ms

Profile along the fiber

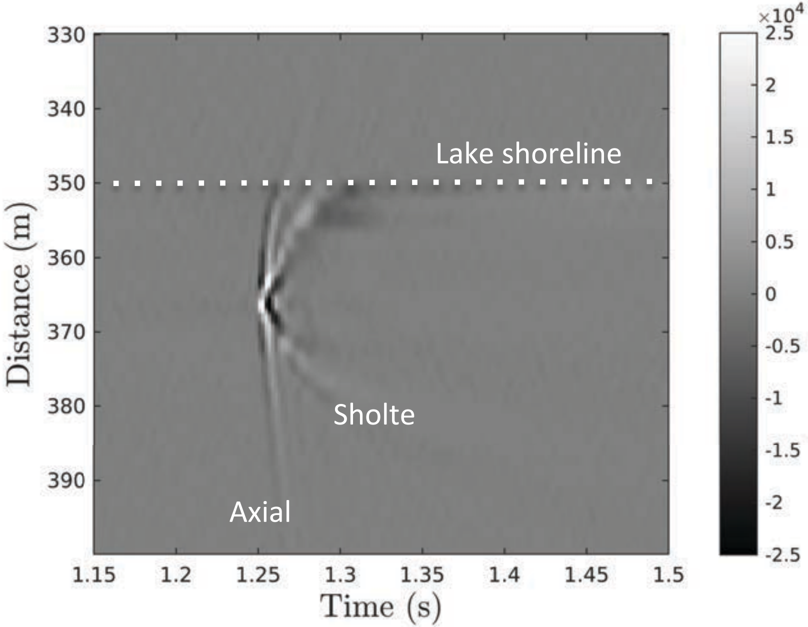


Strain Rate: Filtered data

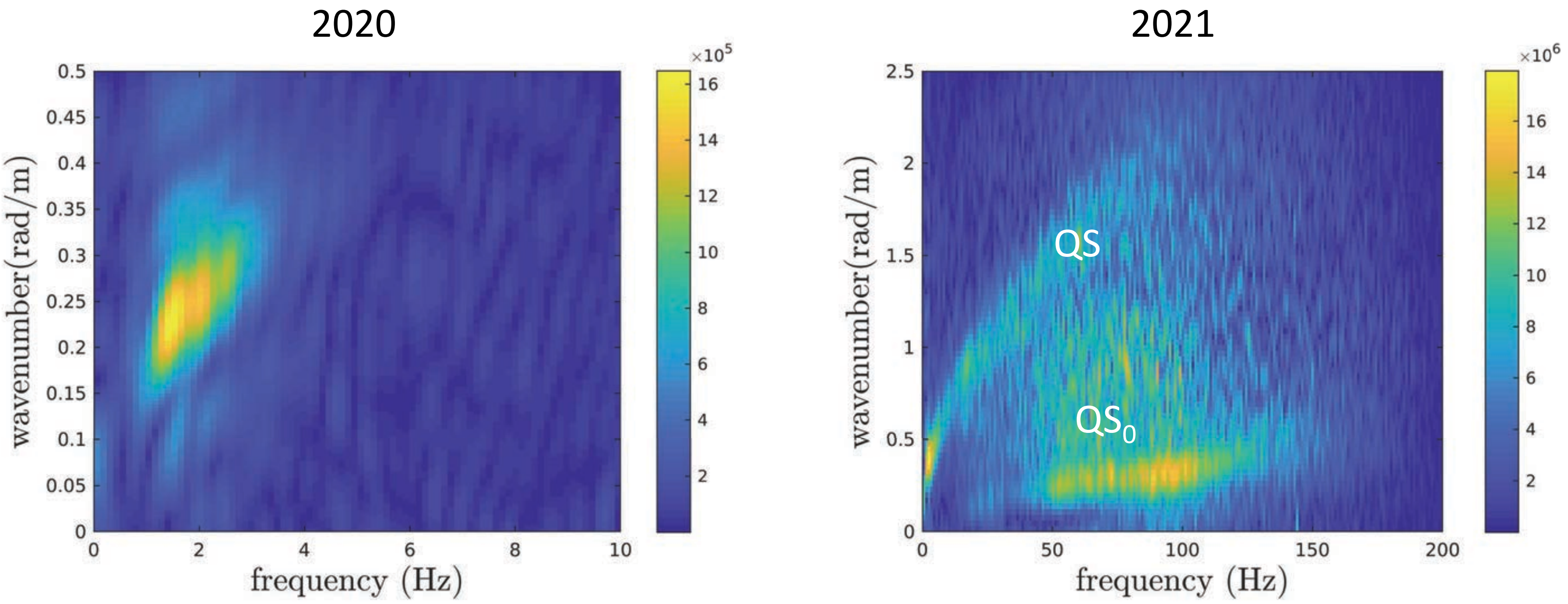
2020 (GL = 10m)



2021 (GL = 2m)



F-K Transform averaged over selected sources



Inversion of « dispersion » curves

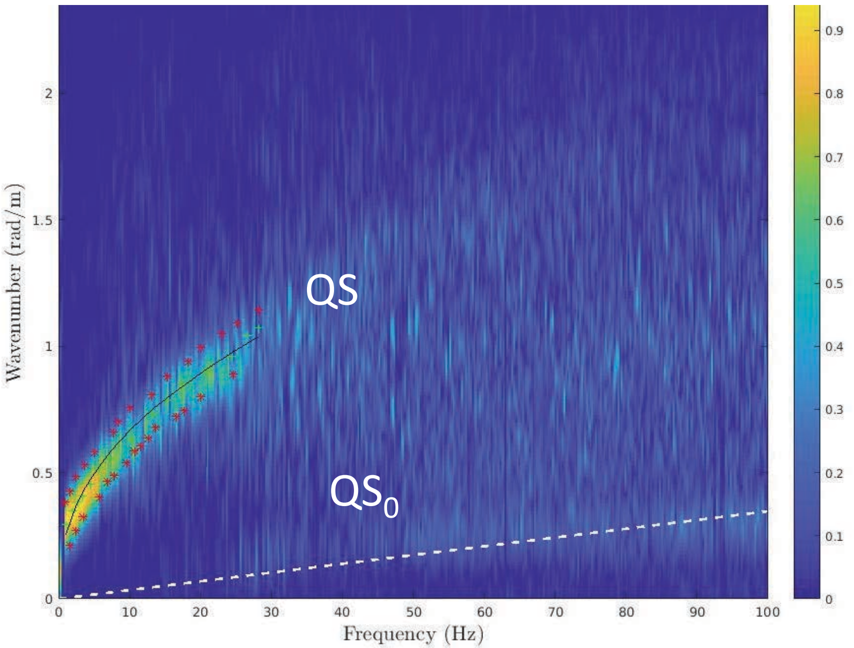
Fundamental axial wave: QS_0

$$c_{QS_0} = \sqrt{\frac{E}{\rho(1-\nu^2)}} \quad (1)$$

Fundamental Sholte wave: QS

$$\left(\frac{\omega}{c_{QS}}\right)^4 - \frac{h\rho\omega^2}{D(h)} - \frac{\rho_w}{D(h)}\left(\frac{\omega^2}{\sqrt{\left(\frac{\omega}{c_{QS}}\right)^2 - \left(\frac{\omega}{c_w}\right)^2}} - g\right) = 0$$

Dispersion curve enhanced by svd filtering (Moreau et al. 2017) using several shots



Assuming ν=0.33 (standard ice value), eq. 1 gives **E** and eq. 2 yields **h**

Results and Conclusions

2020 observation	
90 cm	snow
30 cm	Snow + water
10 cm	ice
30 cm	Ice + water
100 cm	ice

2021 observation	
25 cm	Wet snow
45 cm	Snow + water
60 cm	ice

Results

2020: assuming ρ = 915 kg/m^3 ; E = 9.4 GPa; $\nu = 0.33$
h = 0.56 m using 1-5Hz band

2021 => assuming ρ = 915 kg/m^3 ; $\nu = 0.33$
V_{QS0}=1800 m/s; **E = 3.4 GPa; h = 0.55 m** using 1-30 Hz band

Conclusion

DAS and optical fibers seem appropriate for ice seismic monitoring, although the real Frozen structure is more complex than a single ice layer.
Next step will be to experiment the method on thicker and stronger ice pack and monitor The structure along time

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