Recovering and monitoring the thickness and elastic properties of sea ice from one month of seismic noise in Svalbard

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Context

Decline of Artic sea ice

Rate faster than that forecasted by climate models (ice extent and averaged thickness)

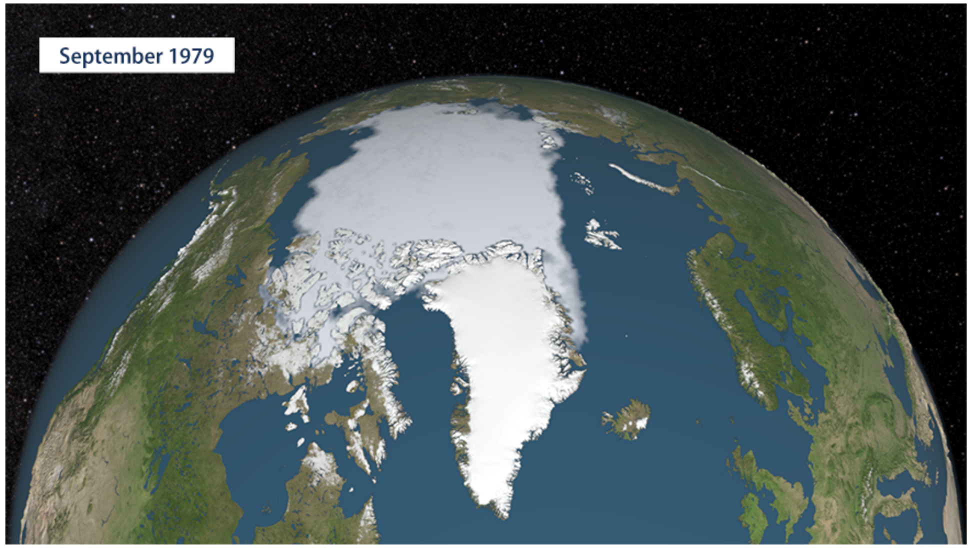
Sea ice-free Arctic :

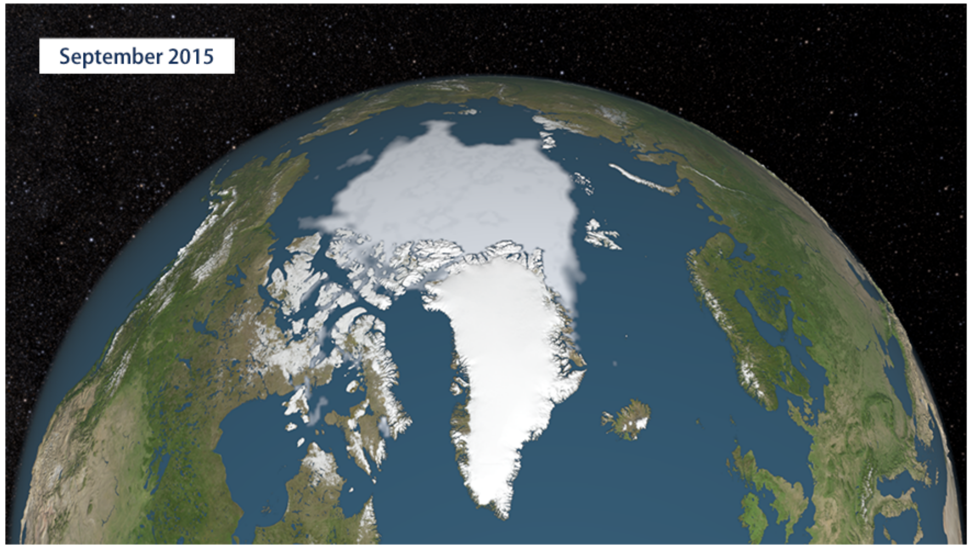
2005 : Sea ice-free Arctic in **2100** (*)

2012 : Sea ice-free Arctic in **2050** (**)

2019 : Sea ice-free Arctic as early as **2030** (***)

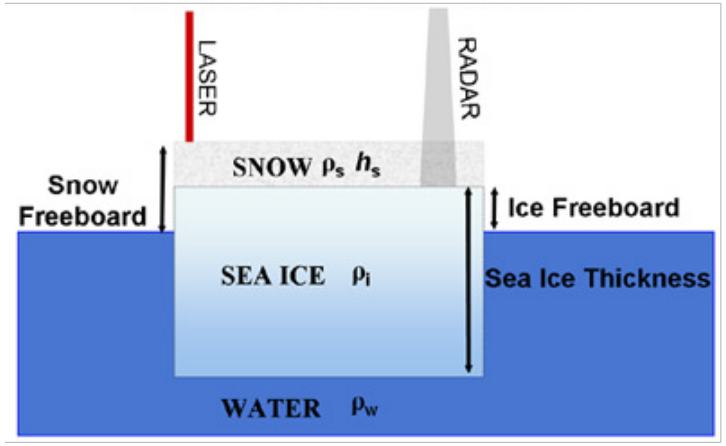
(*) Artic Council and Intergovernmental Panel on Climate Change Fourth Assessment Report, 2005
(**) World Climate Research Programme Coupled Model Intercomparison Project Phase V, 2012
(***) Screen & al. 2019



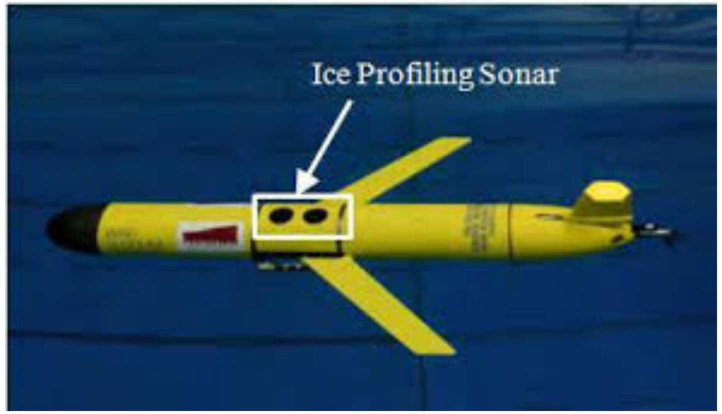


Credit : NASA (National Aeronautics and Space Administration). 2016.

Existing methods to measure ice properties



Credit : National Oceanic and Atmospheric Administration



Credit : IEEE xplore

Credit : Eric Larose

Radar or laser methods by satellite

Thickness estimate by freeboard measurements

- Low precision and spatiale resolution

Sonar methods

+ Better measurements

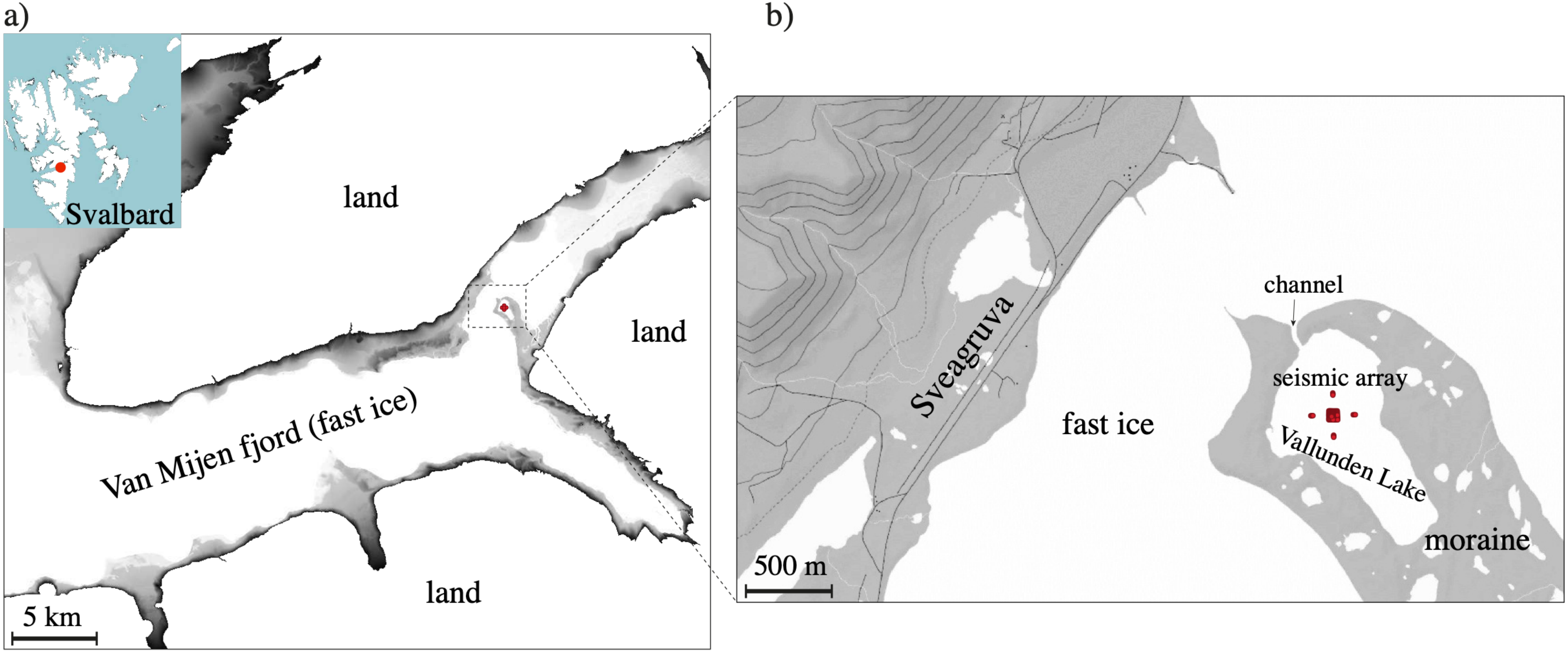
- Costly acquisition and difficult to set up

Seismic methods

Since 15 years : development of passive seismic methods

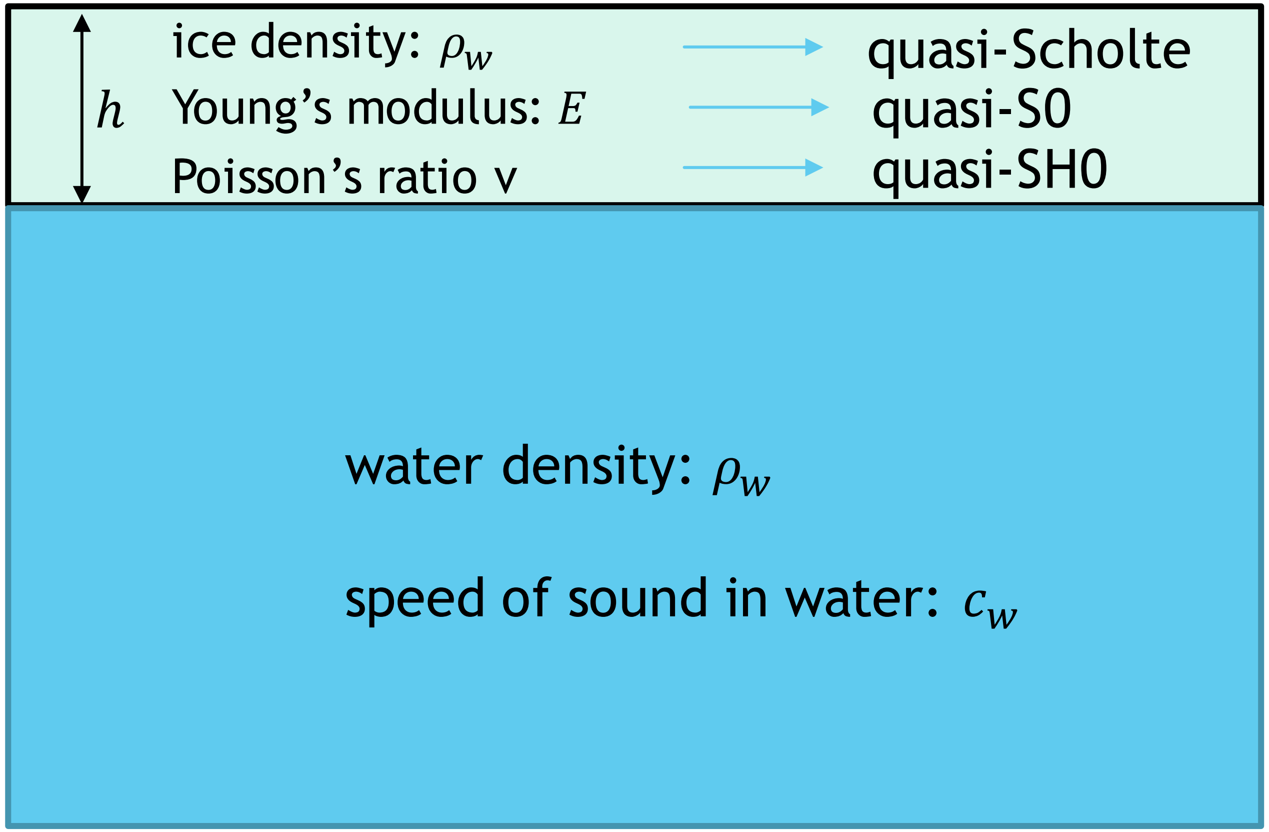
+ Total autonomy of recording

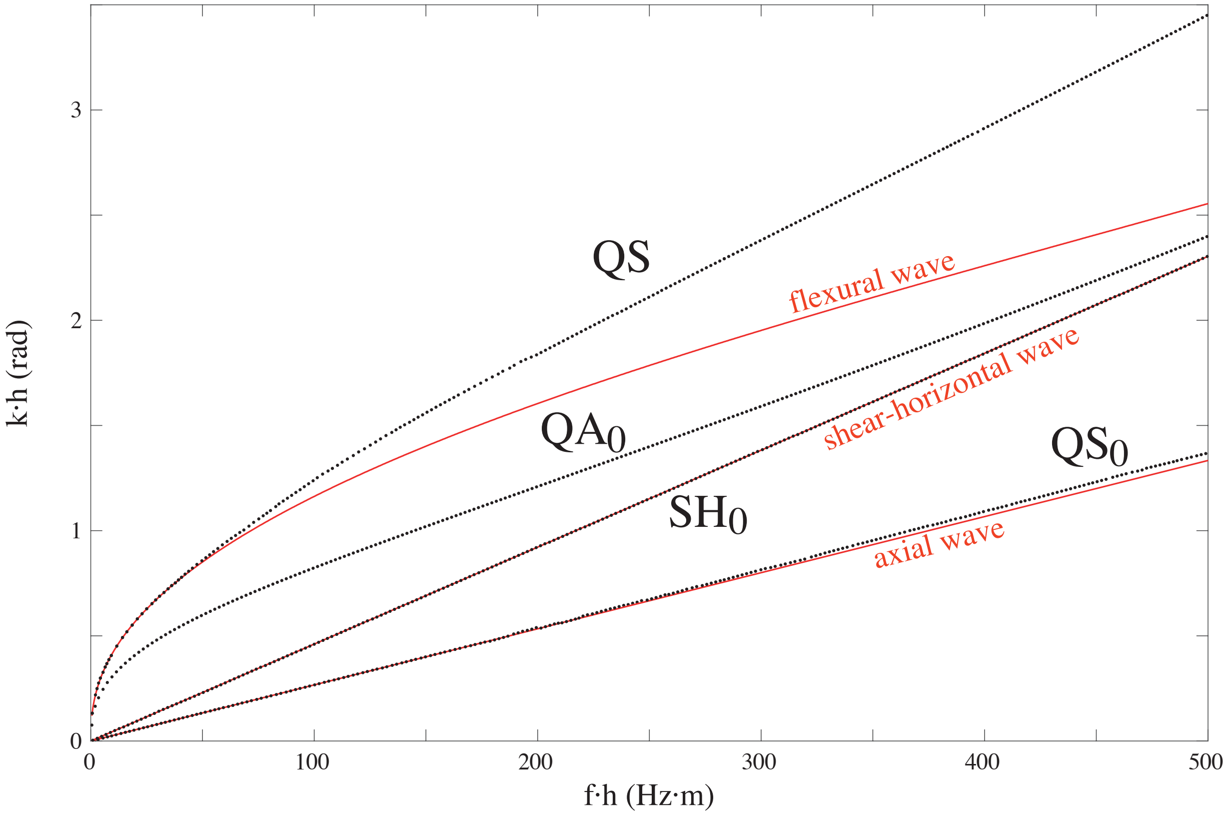
Location of study area



(a) Location of the seismic array in the Van Mijen fjord near Sveagruva (Svalbard), with (b) a zoom around the array area in Vallunden Lake, a part of the fjord that is surrounded by a moraine and connected to the fjord by a channel. The gray scale show land which altitude is less than 25 m. All land above
25 m is shown in white to emphasize the shore line. Moreau & al. 2019

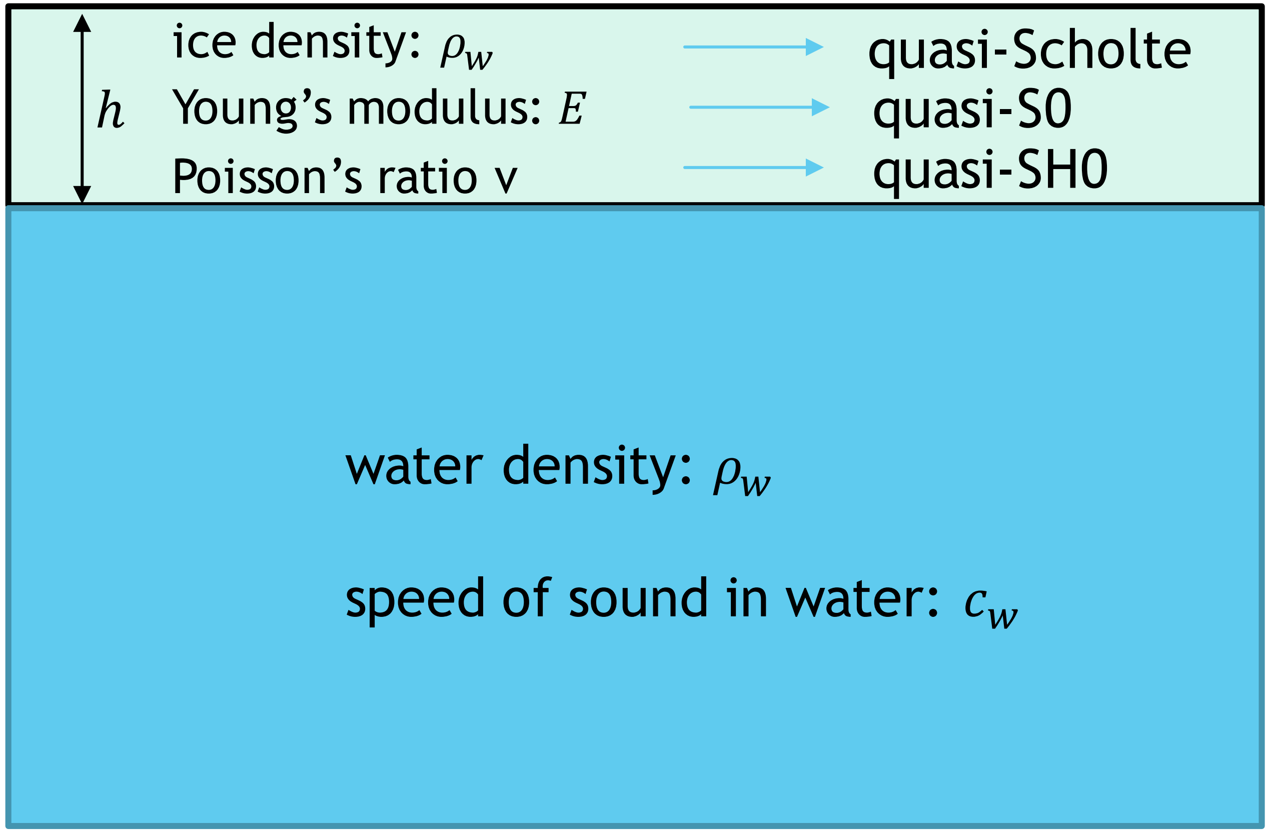
Direct problem modelisation





→ Low frequency-thickness regime assumed (typically less than ~ 50 m.Hz), allowing asymptotic approximation for the phase-velocities of the fundamental guided modes [Stein et al, J. Geophys. Res. 1998]

Direct problem modelisation



$$c_{QS0} = \sqrt{\frac{E}{\rho(1-\nu^2)}}$$

$$c_{QSH0} = \sqrt{\frac{E}{2\rho(1+\nu)}}$$

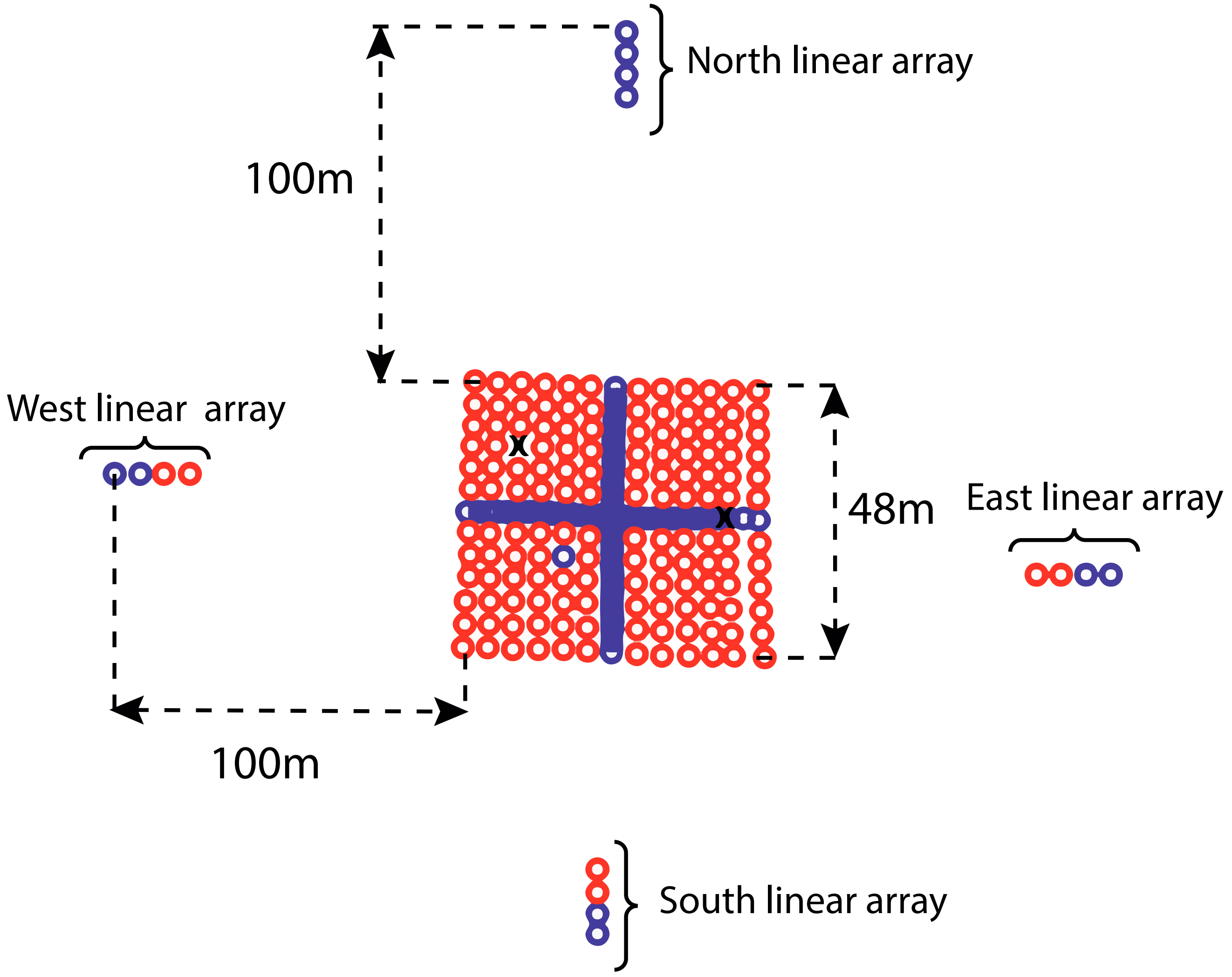
→ Low frequency-thickness regime assumed (typically less than ~ 50 m.Hz), allowing asymptotic approximation for the phase-velocities of the fundamental guided modes [Stein et al, J. Geophys. Res. 1998]

Direct problem modelisation

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

$$D = \frac{Eh^3}{12(1-\mathrm{v}^2)}$$ (rigidity bending)

Methodology



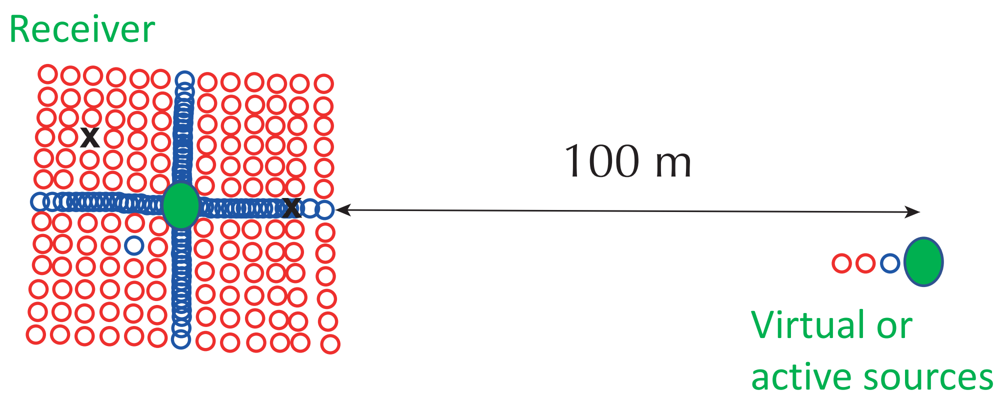
1. Calculation of noise correlation function

2. Stack calculation with optimisation using beamforming to find noise sources in-line with stations pairs.

3. Extraction of dispersion curves from frequency-wavenumber analysis.

4. Inversion with Simulated annealing to find global minimum, followed by MCMC sampling to find the probability density function of the parameters.

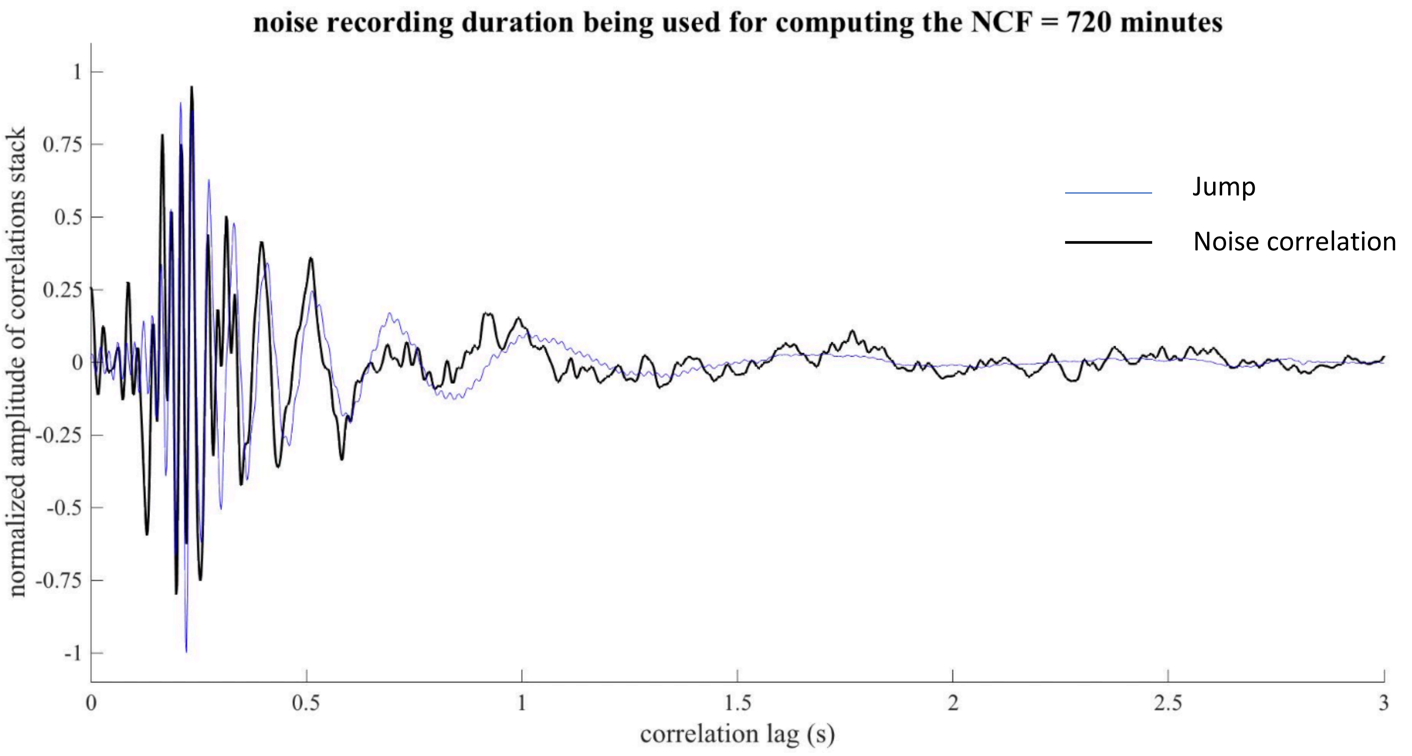
1. Calculation of noise correlation function



<u>Parameters of correlation calculations</u>

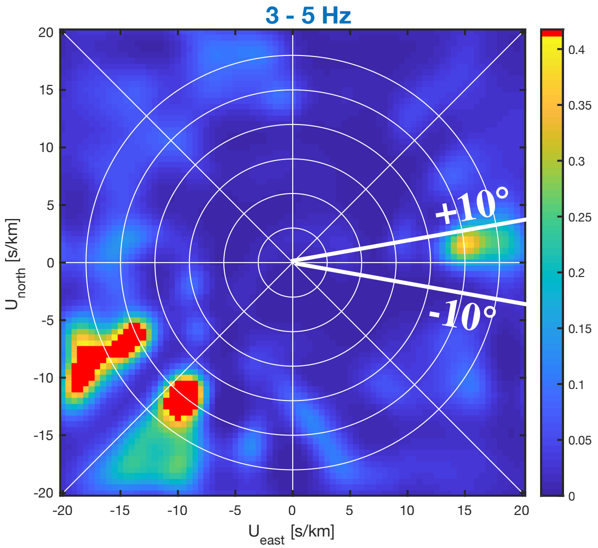
Duration of correlation windows : 5 min

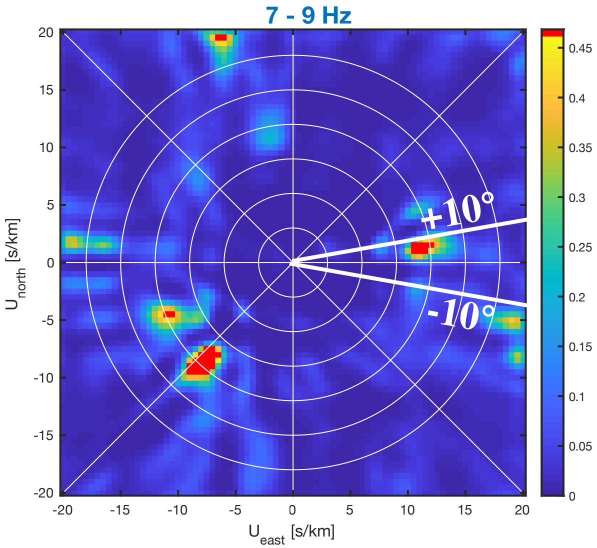
Spectral normalization

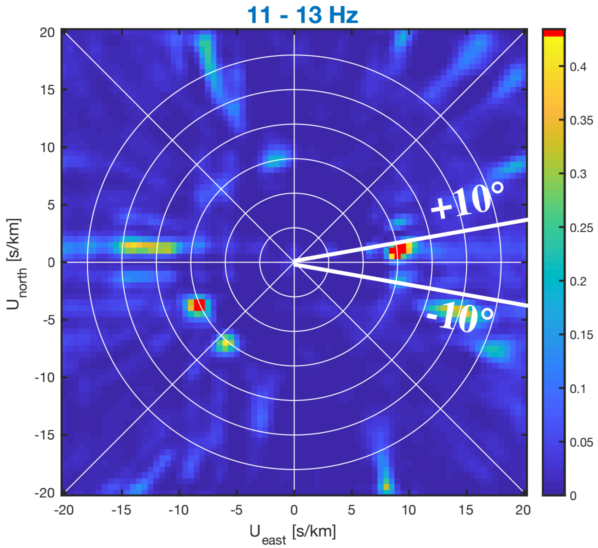


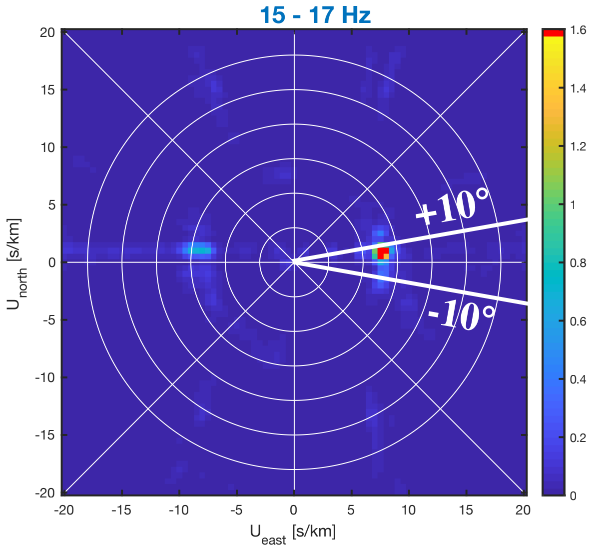
Noise correlation function from 12 hours of continuous noise recording (black), from the jump (blue)

2. Stack optimization by beamforming

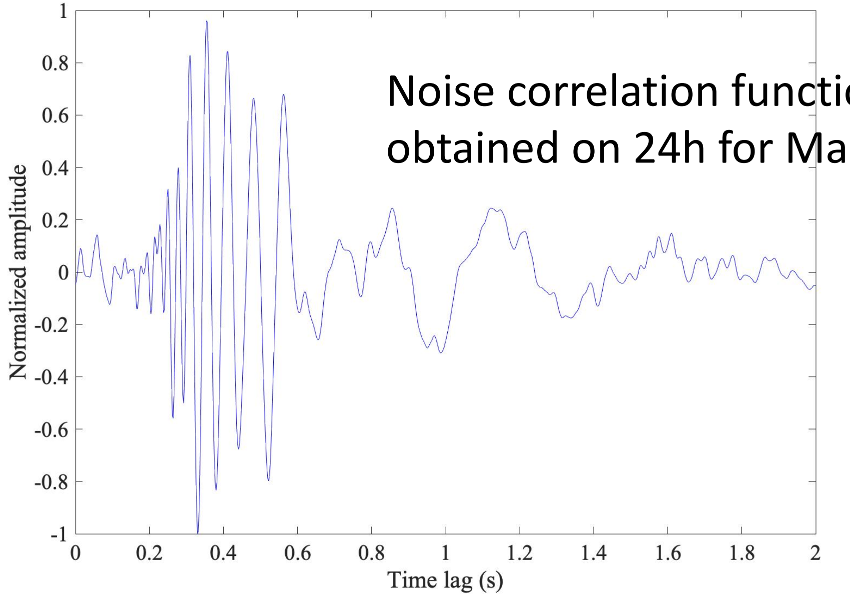




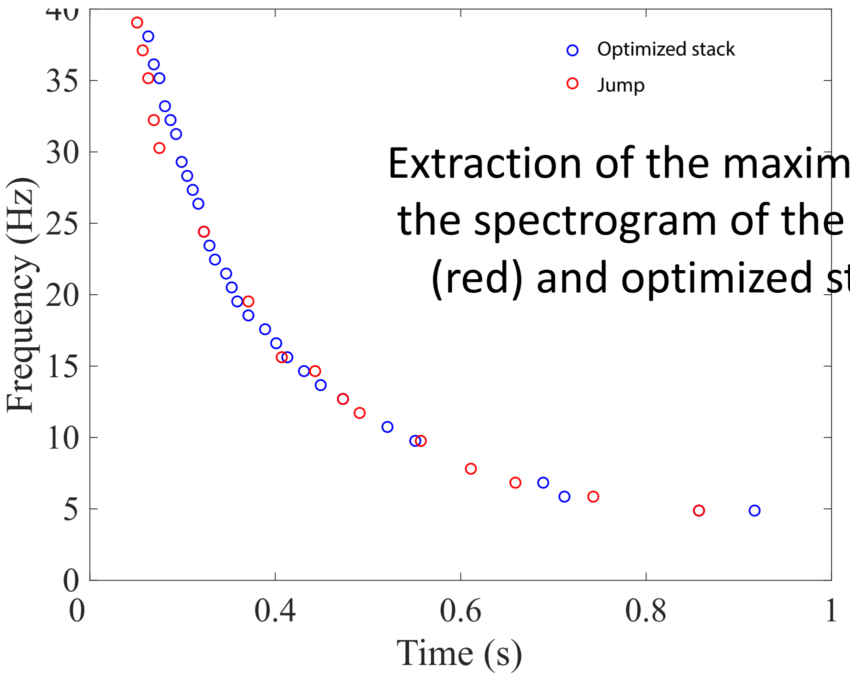




Beamforming realized on a five-minute window over 4 frequency-band for the March 3



Noise correlation function obtained on 24h for March 3



Extraction of the maximum of the spectrogram of the jump (red) and optimized stack

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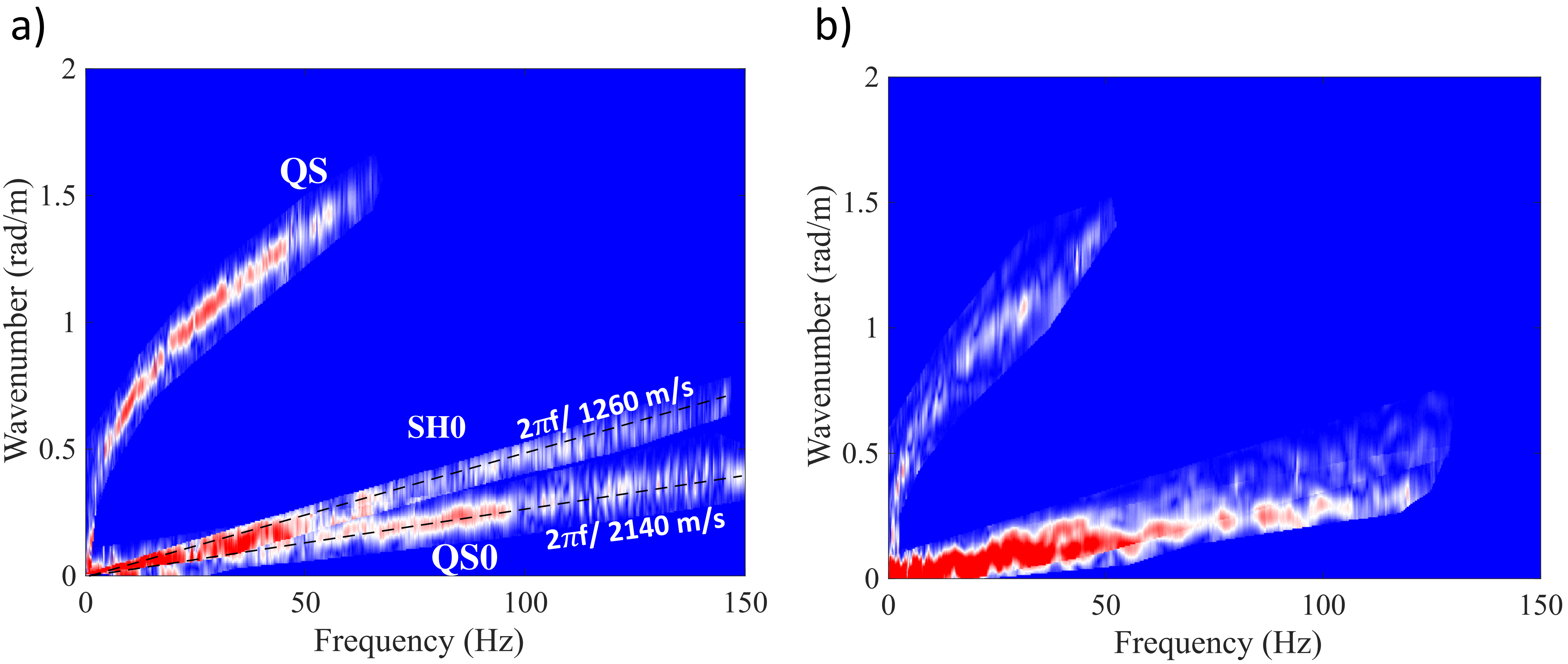
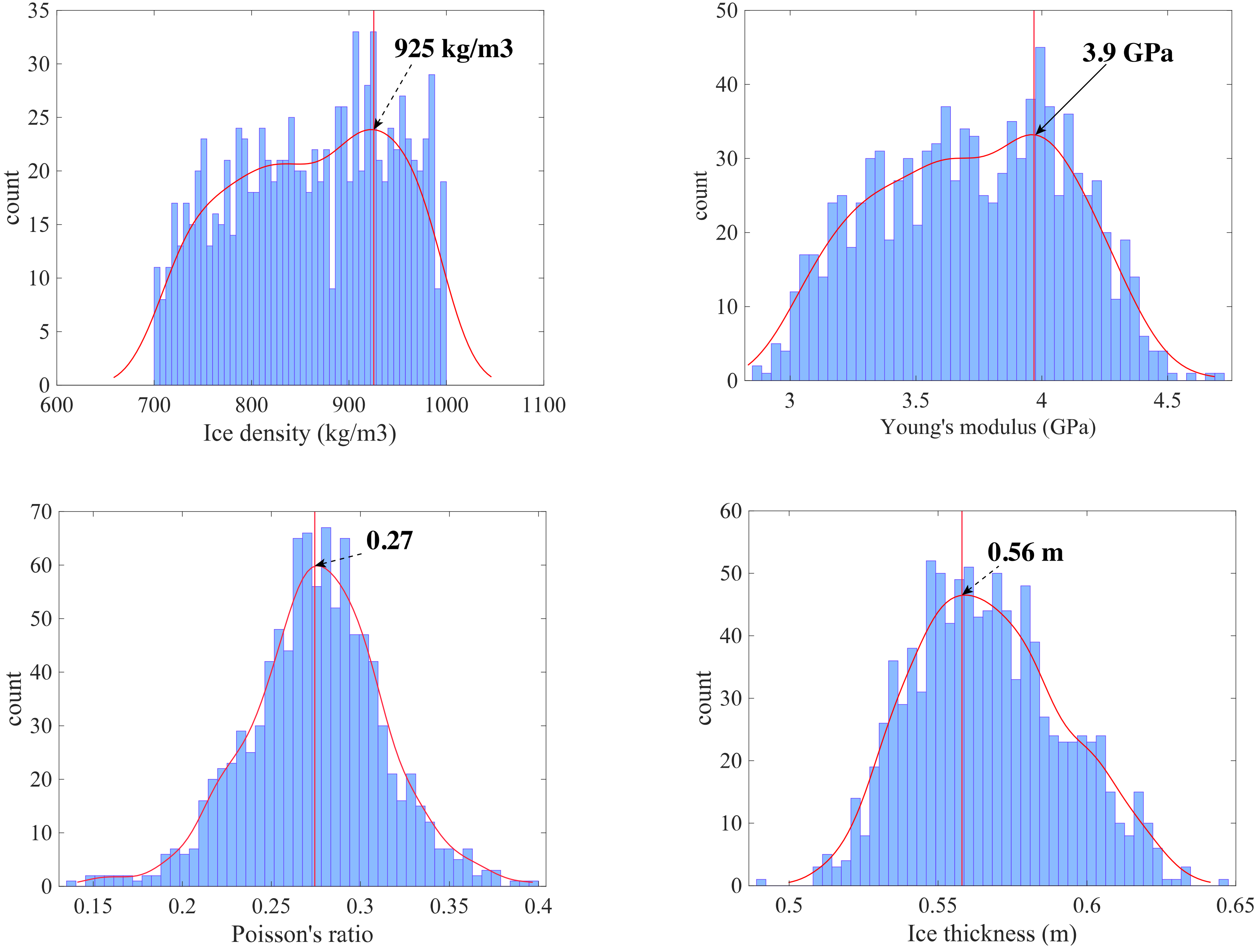
3. Extraction of dispersions curves



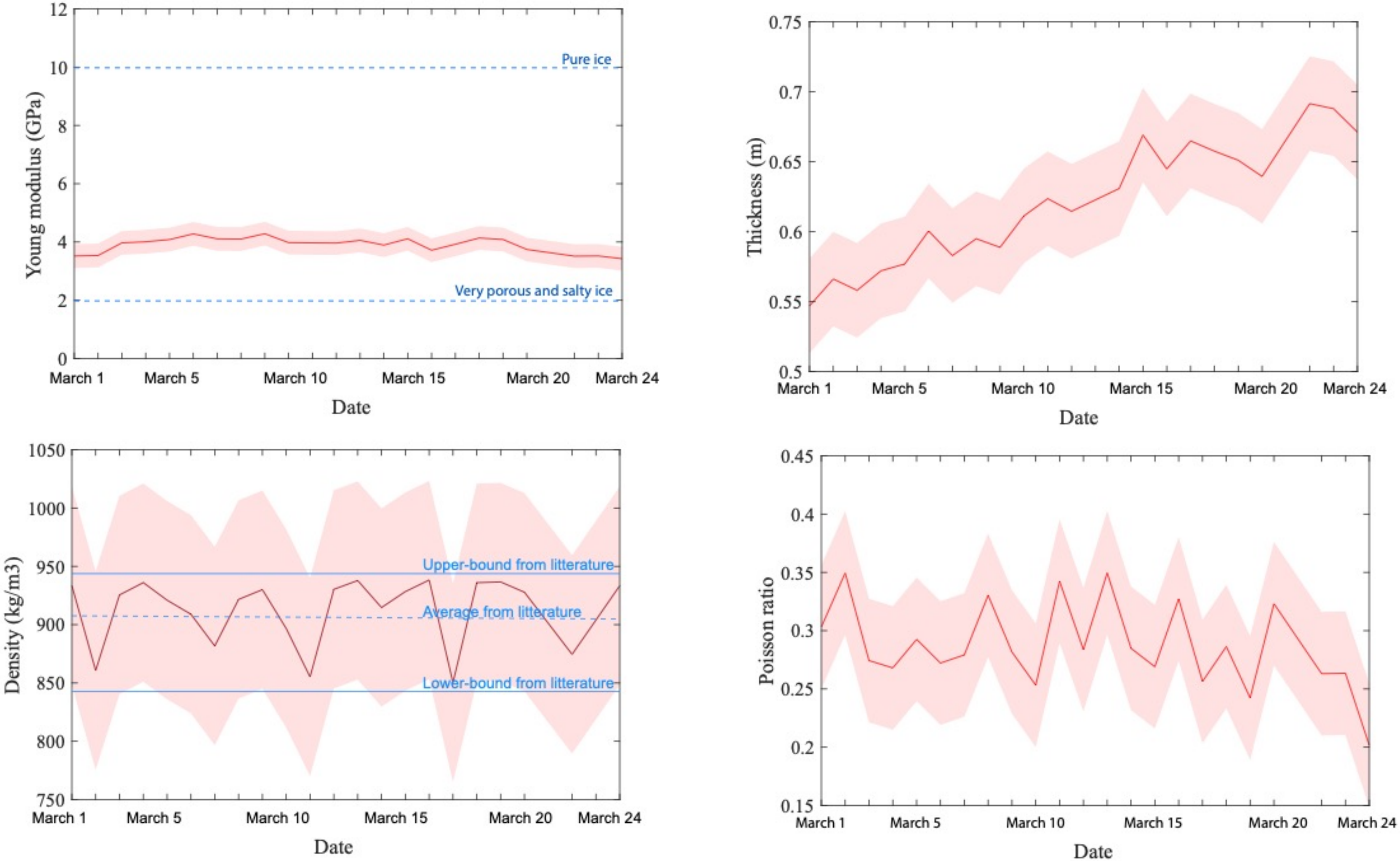
Dispersion curves for 8 March calculated from stack calculation with optimisation using beamforming (a), stack without optimisation (b)

4. Inversion by simulated annealing and MCMC sampling



Probability density function of the ice thickness and mechanical properties, estimated from the MCMC algorithm.

Results direction East West



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Conclusion

- Thickness, Young modulus and Poisson's ratio estimations are well constrained and coherent with litterature

- Thickness is in very good agreement with our onsite ground penetrating radar surveys and ice drillings

- Only the density is less well constrained but the values are within the expected intervals for a first ice according to the literature

Next step : application of a new method to estimate sea ice thickness and elastic properties from passive recordings of the ambient seismic field with a minimal number of geophones