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Laboratory Experiments and Modeling of Hydraulic Fractures in Briny Ice

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Background

- Ice shelves buttress grounded marine ice sheets and their fracturing can lead to rapid sea level rise (Rignot et al. 2004).
- Motivated to understand the stability of ice shelves with regard to the propagation of large, through-cutting fractures called rifts, recent work has shown that salt accretion slows rift propagation in suture zones (McGrath et al. 2014).
- Water experiences a well-known volume expansion by ~9% during freezing. This volume expansion creates stresses that lead to the creation of fractures (Figure 1). Yet a very simple at-home experiment shows that the addition of salt inhibits fracture formation. Why?

Figure 1. Sample with Fractures; Air Temperature: −30 °C; Salinity: 0.25 g/l

Saltwater

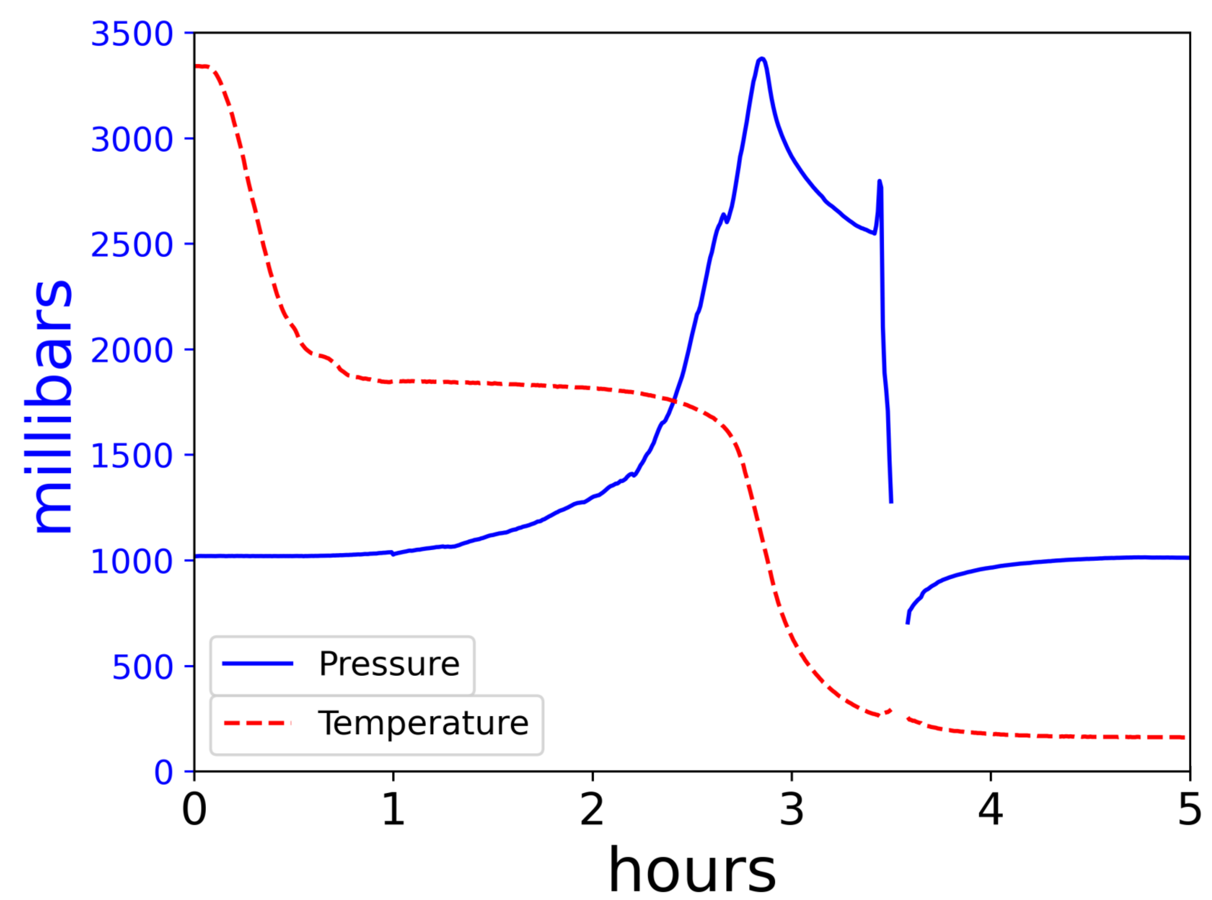

Figure 3. Ambient air temperature; −30 °C. Salinity: 6 g/l. Estimated $\dot{P}$ value of 0.87 mbar/s.

Freshwater

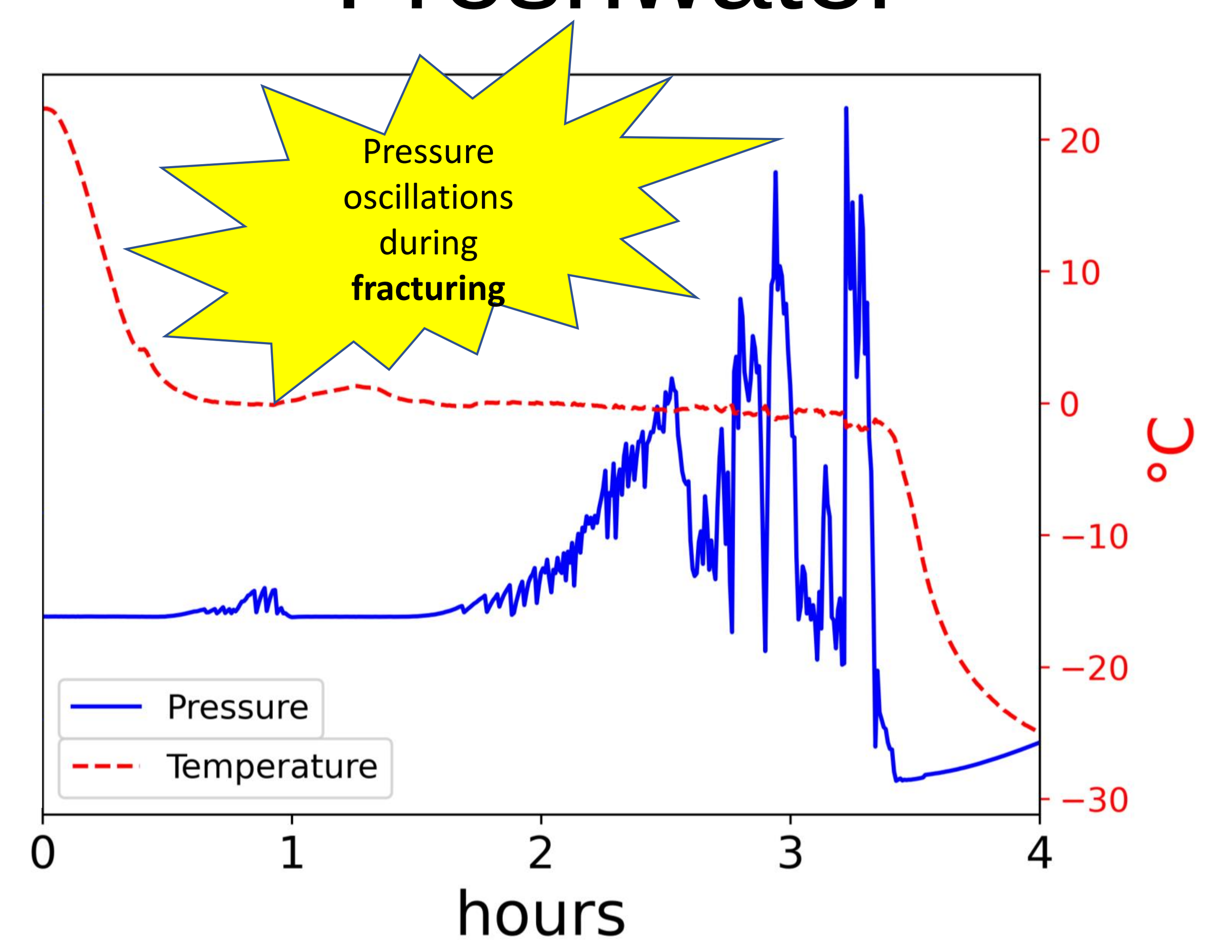

Figure 4. Ambient air temperature: −30 °C. Salinity: 0 g/l. Estimated $\dot{P}$ value of 0.91 mbar/s.

Method

Figure 2. An Associated Environmental Systems Environmental Chamber (Model SK-2101) held ambient air temperatures constant below 0 °C.

Conducted freezing experiments in Ziplock bags filled with 950 ml NaCl solution. Temperature and pressure measured with an MS5803-05BA sensor.

Fracture Stability

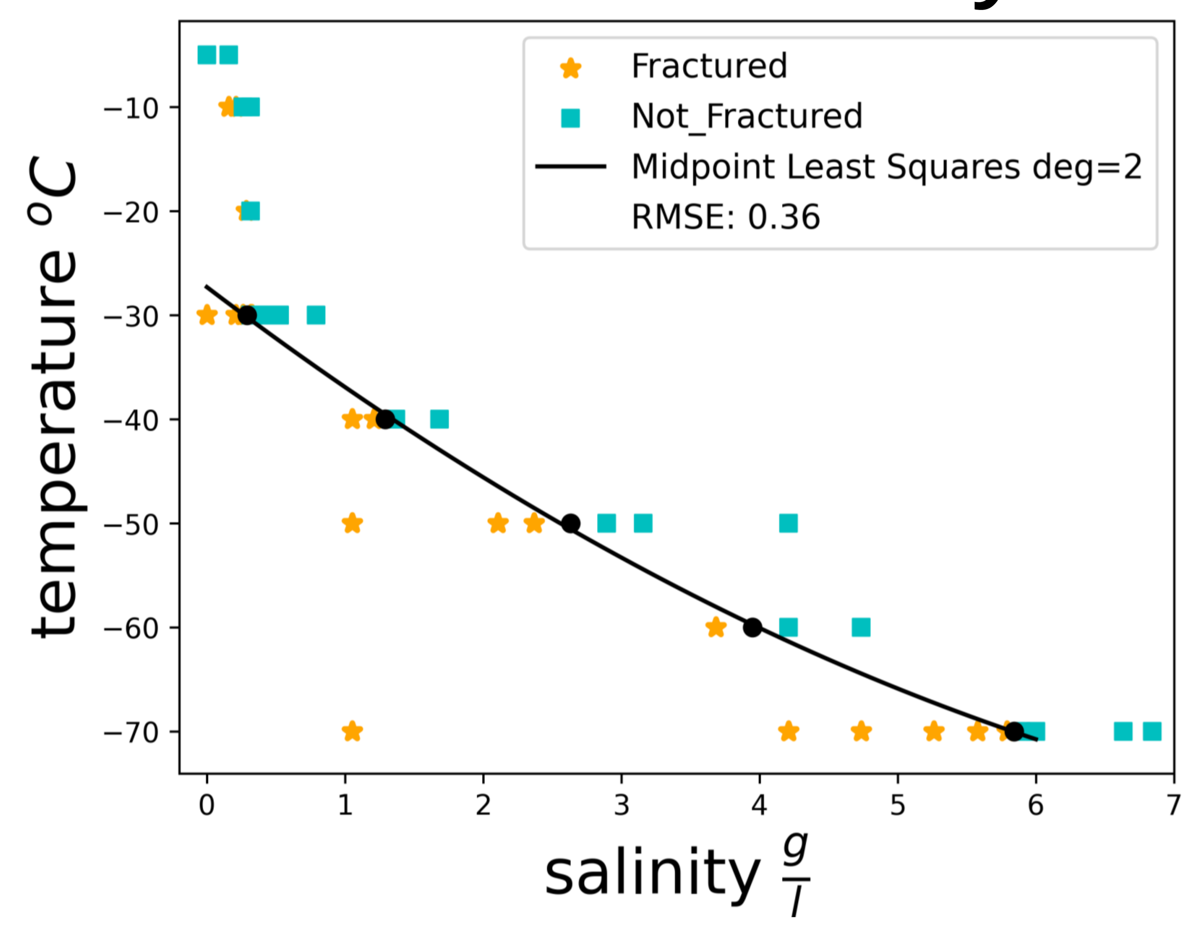

Figure 5. The experiments demonstrate that fracture occurrence disappears beyond a critical curve of salinity and temperature below −30 °C.

Discussion

- Our main result is that increased salinity is associated with decreased fracture occurrence (Figure 5).
- One of the classic problems with ice fracturing experiments is how to secure the sample to apply a load. Our experimental design avoids this problem by using the volume expansion during freezing as the "applied load" to instigate fracture.
- Macroscopic pressure differences do not appear to be the cause of fracture formation in fresh versus salty ice (Figures 4 and 5) because these experiments generally reach similar overall pressures regardless of salt content.
- We hypothesize that fractures are inhibited due to the formation of poroelastic fracture **cohesive zones** due to salt rejection at the scale of individual ice crystals.
- Future work will test this hypothesis using the predictions of simple models.

References

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