Project report: *Energy transfer from wind to waves in the Antarctic Marginal Ice Zone*

Introduction

Sea ice along the Antarctic continent is continuously exposed to energetic waves coming from the open water swatch of the Southern Ocean which, if sufficiently strong, can transform the Marginal Ice Zone (MIZ) in a matter of a few hours [1,2]. To model the effects of waves on sea ice for navigational, weather, and climatological purposes, we need to understand how waves and sea ice interact. While observations of waves in sea ice are becoming more accessible, observations of energy input from wind to waves in the presence of sea ice remains virtually absent due to methodological challenges. Because of the absence of field observational data on wave growth by wind in the MIZ, forecasting models have to rely on unverified assumptions and knowledge of wave growth in the open ocean, leading to significant uncertainties in model forecasts and interpretation of observations of waves in sea ice. *In this pilot-project, I attempt to measure the transfer of energy from wind to waves in the Antarctic MIZ through the development of a low-cost experimental set-up*.

As COVID-19 restrictions have disrupted this project at several fronts, I will report the preliminary results here only, followed by a brief overview of expected future activities related to this project.

Instrument development

Figure 1: final design of instrument.

In the open ocean, waves grow as "*the wind effectively pushes the water surface down where the wave surface is moving down and pulls the water surface up where the surface is moving up*" [3], thus, to measure wind-wave growth, both the vertical motion of the sea ice and the surface pressure need to be measured concurrently. Measuring its vertical motion is relatively straightforward using today's off-the-shelf technology, but measuring the surface pressure is complicated for two reasons: (1) the wind introduces noise in the measured pressure signal whilst the wave-induced pressure is very small, (2) typical pressure sensors need to be exposed to the air but cannot be exposed to moisture. I therefore designed a static pressure port which restricts the impact of dynamic pressure. The pressure port is 3D-printed and contains a breathable film that is permeable to air but not moisture. The pressure port is compact as to limit the impact of the instrument on the air flow around the instrument. The electronics are contained in a $14 \times 14 \times 9$ cm waterproof enclosure, the pressure port is elevated 30 cm above the ground. See Fig. 1 for a photo of the instrument design.

To test the accuracy of the instrument in measuring pressure the probe was fixed to a rotating wheel, which mimics the orbital motion of waves. The tests were repeated for different wave amplitudes 'a' and wave periods 'T'. Except for the smallest wave amplitude tested, errors are smaller than 5%

for the relevant range of wave periods observed in the field (Fig. 2), and remain constant when increasing the amplitude, meaning that the measurements can be corrected for this bias. It is worth mentioning that the amplitude of 2.5 cm (Fig. 2, left plot) leads to a theoretical pressure amplitude below the accuracy provided by the sensor manufacturer. As such, the error results for this case are in line with expectations.

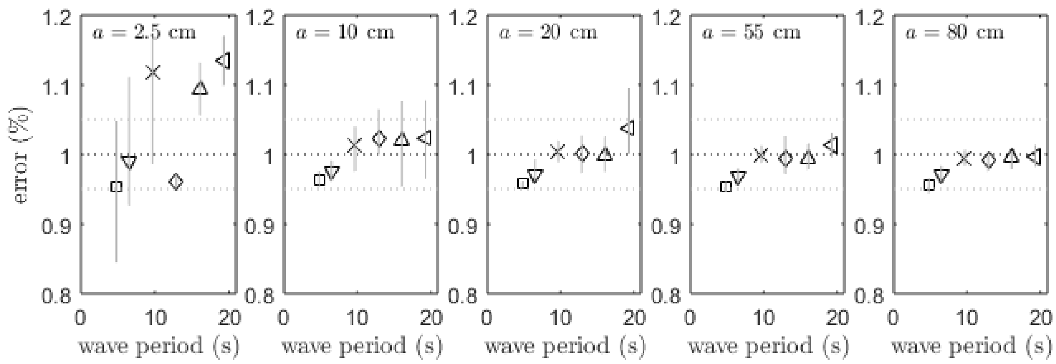

Figure 2: error of the measured pressure as tested on a rotating wheel for different wave periods and wave amplitude 'a'.

To identify the impact of wind noise on the pressure observations, the instrument was brought outdoors at winds of about 5 m/s. As the rotating wheel cannot be brought outside, waves were mimicked by holding the instrument in the air while performing squats. This was done for three different frequencies (Fig. 3). During a brief period of time, the instrument was exposed to a wind gust of 10 m/s, visible by the elevated noise in recorded pressure (see Fig. 3, middle plot). From the wavelet coherence between the measured pressure and vertical acceleration, a strong correlation can be observed at the excitation frequency (Fig. 3, bottom plot). This correlation is not impacted by the elevated noise during the wind gust event, confirming the functionality of the instrument in estimating wave growth in sea ice.

Planned activities

A total of 6 instruments were constructed and are expected to be deployed in the Antarctic MIZ in November 2023 as part of the Australian Antarctic Science Program. During the cruise, the research vessel will make regular short-term stops to perform 24-hour long data collections of the atmosphere, ocean and sea ice. During these stops, instruments will be deployed and retrieved. This will provide access to the raw data of the instrument from which advanced data analysis can be performed (including wavelet and phase averaging analysis), and the wind-input function can be derived [4]. If successful, this will be the first field observational data of wind-wave growth in the MIZ.

The advanced data analysis is computationally expensive, and it needs to be assessed first if the analysis can be automized. If the data processing can be automized, I plan to extend the design with an Iridium modem to allow for the wind-input function to be transmitted remotely, improving the flexibility of instrument deployment (i.e., without the need of retrieval).

References

[1] Asplin, M. G., Galley, R., Barber, D. G., & Prinsenberg, S. (2012). Fracture of summer perennial sea ice by ocean swell as a result of Arctic storms. *Journal of Geophysical Research: Oceans*, *117*(C6).

[2] Collins III, C. O., Rogers, W. E., Marchenko, A., & Babanin, A. V. (2015). In situ measurements of an energetic wave event in the Arctic marginal ice zone. *Geophysical Research Letters*, *42*(6), 1863-1870.

[3] Holthuijsen, L. H. (2010). *Waves in oceanic and coastal waters*. Cambridge university press.

[4] Donelan, M. A., Babanin, A. V., Young, I. R., & Banner, M. L. (2006). Wave-follower field measurements of the wind-input spectral function. Part II: Parameterization of the wind input. *Journal of physical oceanography*, *36*(8), 1672-1689.

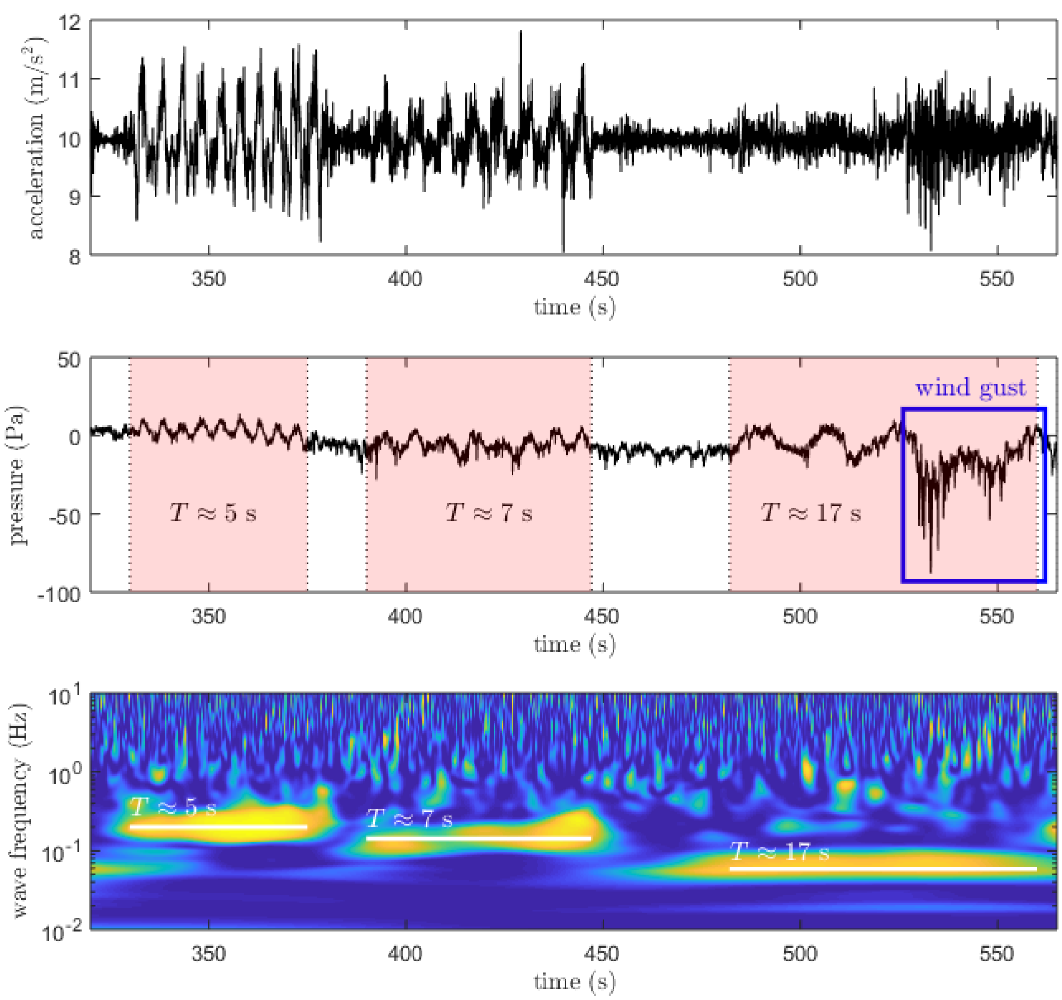

Figure 3: measurements of pressure during wave motions in the presence of wind. (top) vertical acceleration of instruments, (middle) pressure at pressure port, (bottom) wavelet coherence between vertical acceleration and pressure. Background winds are about 5 m/s, wind gust reached 10 m/s.