Wind Waves in Sea Ice of the Western Arctic and a Global Coupled Wave-Ice Model

NATIONAL DEFENSE SCIENCE AND ENGINEERING GRADUATE FELLOWSHIP PROGRAM

In revision at:
Philosophical Transactions of The Royal Society A: Mathematical, Physical, and Engineering Sciences

NDSEG Research Discipline: Oceanography (Arctic and Global Prediction)

VINCENT T. COOPER

University of Washington

Collaborators: Lettie Roach, Jim Thomson, Madison Smith, Sam Brenner, Mike Meylan, and Cecilia Bitz

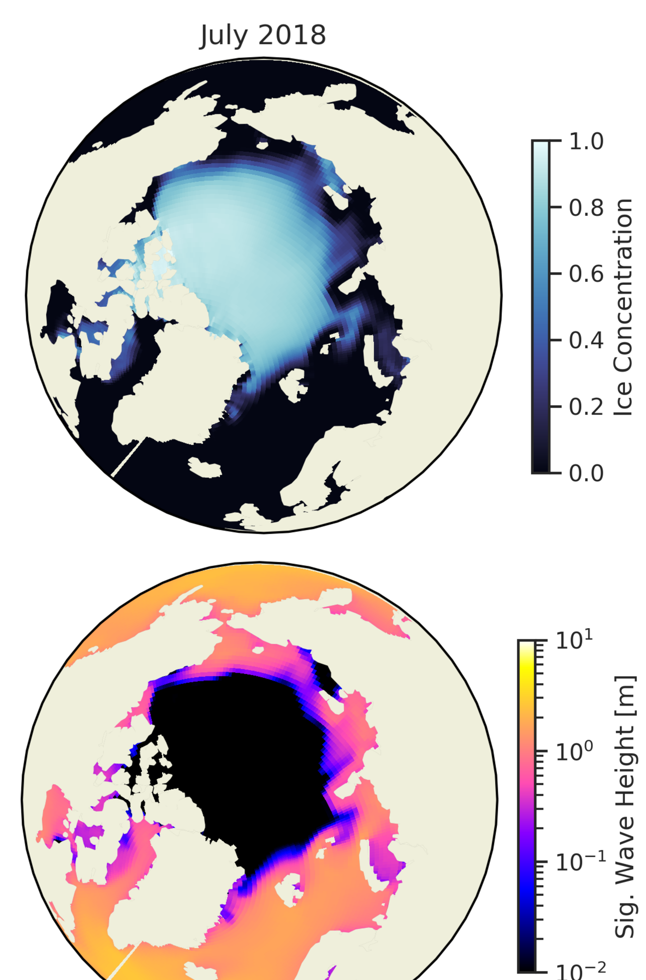
Fellowship Year: 2020

Service: Navy (Office of Naval Research)

Advisor/Mentor: Cecilia Bitz (UW) / Mark Orzech & Erick Rogers (NRL)

INTRODUCTION

- **Ocean surface waves** now have a much greater role in the **Arctic Ocean**
- Arctic climate warms → **sea ice thins and retreats** → remaining ice cover is exposed to **bigger waves**
- Ice fracture, ocean mixing, eddy generation, and **rapid ice melt events are impacted by waves in polar seas**
- Observations of wave-ice interaction are rare, constraining coupled wave-ice models is a major challenge
- Forecast and climate models have deficient (or no) representation of wave-ice physics

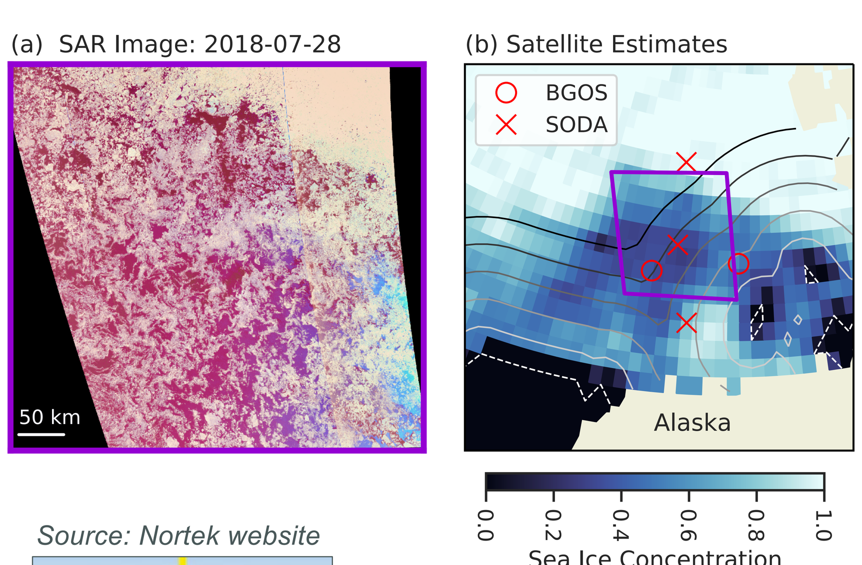


(Right) Modeled sea ice concentration and sig. wave height (July 2018)

METHODS

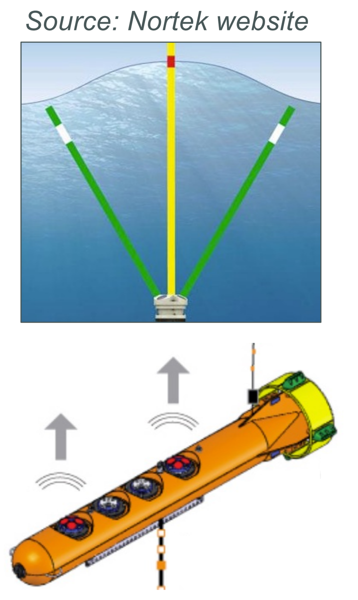
IN SITU OBSERVATIONS

Five subsurface moorings from **BGOS** and **SODA**, continually **sampling all year** from **2012-2020**.



Contours indicate **distance (Δ^{dist}) inside Marginal Ice Zone (MIZ).**

Source: Nortek website



Adapted from SODA DRI, Lee et al. (2016)

When moorings are under partial ice cover, surface wave signal must be sufficiently energetic to yield valid wave measurements.

COUPLED WAVE-ICE MODEL

Model Configuration

Roach et al. (2019) Global Coupled Wave-Ice Model (using CESM2 framework)

Prescribed Atmosphere
JRA-55 Reanalysis

Sea Ice
CICEv5 + floe size distribution

Waves
WavewatchIII

Slab Ocean
(represents ocean mixed layer)

Nominal 1° global grid, ~50 km resolution in Arctic

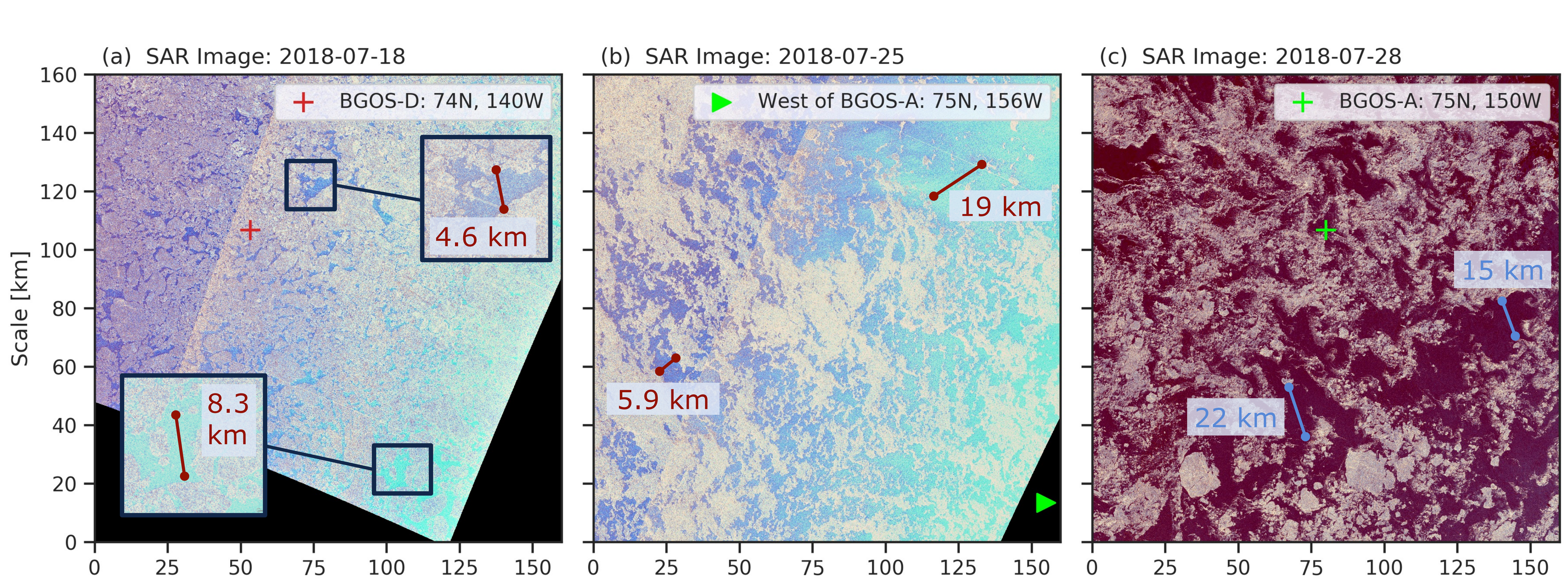
Wave attenuation can depend on:
- Ice concentration
- Ice thickness
- Floe size

Ice floe fracture and formation depend on wave spectrum.

Experiments run for 1 year (2018) varying:
1) Wave attenuation rates and
2) Wind input for wave growth in ice

SAR IMAGES: JULY 2018 MELT EVENT

Images of the marginal ice zone (MIZ) during a melt event while local wind waves were observed. Annotations indicate characteristic fetch in open-water patches between ice floes.

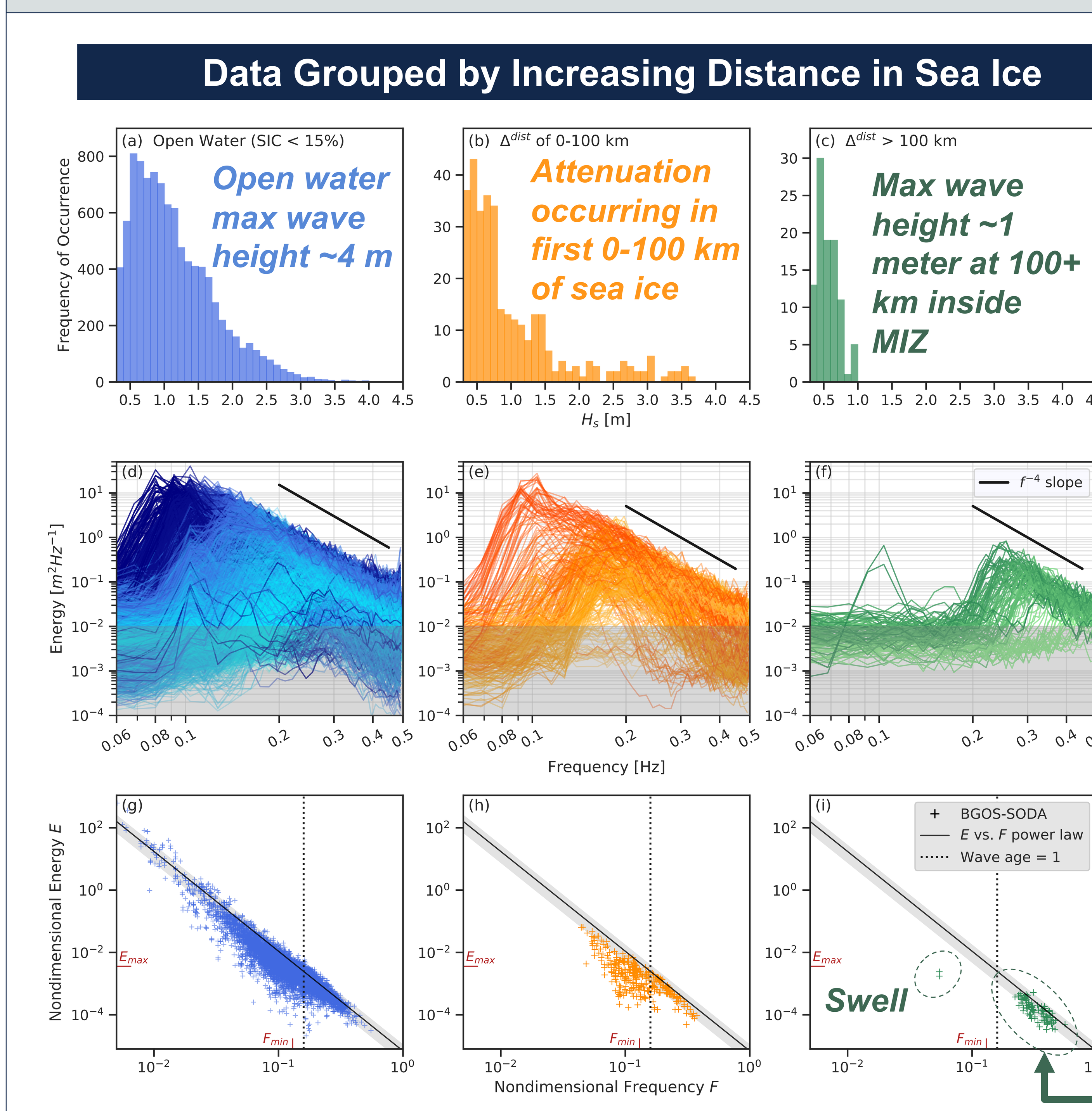


Anticipated Completion: June 2025 (M.S. + Ph.D.)

Contact: vcooper@uw.edu

RESULTS

LONG-TERM OBSERVATIONS IN THE BEAUFORT SEA



Histograms of Significant Wave Height, aggregating all BGOS-SODA moorings

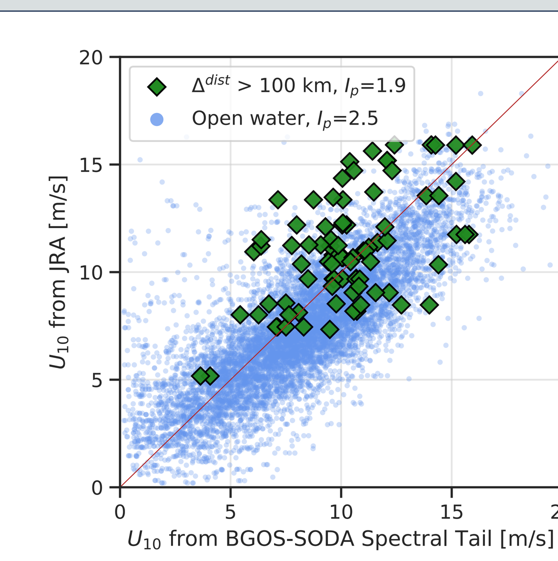
Hourly **wave spectra**, colored by peak frequency *(Detection limit marked with gray shading)*

Fetch Scaling of Energy vs. Frequency. (Black line) Power law for local fetch-limited wind-wave generation

Local wind waves generated 100+ km inside MIZ. Implied fetch required: 5-20 km *(see SAR images, lower left).*

VALIDATION: ESTIMATES OF 10-M WIND SPEED

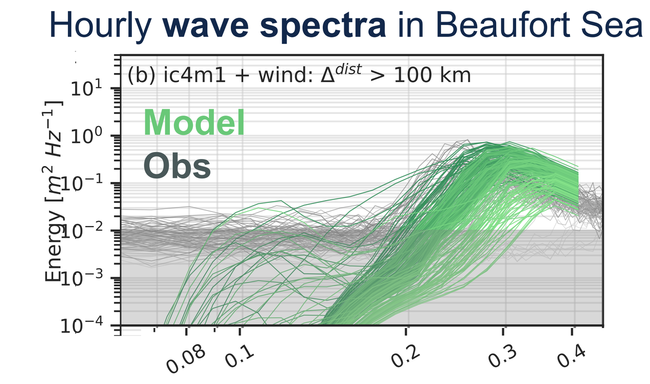
- 10-meter wind speed (U_{10}) can be estimated from the spectral tail (Thomson et al. 2013, Voermans et al. 2020)
- U_{10} predicted by moorings (from 30-45 meters beneath ocean surface) compares well with reanalysis, **confirming that waves observed at 100+ km inside MIZ are locally generated**



MODEL EXPERIMENTS: SIMULATING LOCAL WIND WAVES IN ICE

- **Coupled wave-ice model (green) can simulate local wind waves in partial ice** (100+ km inside MIZ) when attenuation of high-frequency energy is relatively weak
- **Agreement with observations is improved by allowing more wind input** for wave generation in ice cover

Hourly **wave spectra** in Beaufort Sea



BENEFITS TO DOD

- Maritime activities are increasingly possible in the Arctic, and we are **defining the current (evolving) wave-ice climate in the Arctic using in situ observations**
- We are enabling **high-precision forecasts of weather, waves, and sea ice**
- Improving **prediction of Arctic climate across timescales** by including wave-ice interactions **in an integrated ocean-ice-wave-atmosphere model**
- **Identified a local wave regime in partial ice**, impacting physics and navigators

CONCLUSIONS

- **Beyond 100 km inside marginal ice zone**, long-term observations in Beaufort Sea indicate **~0.5 meter waves are locally generated in open water patches**
- **Local wind waves** in partial sea ice cover **may enhance ice melt** by ice fracture, ocean mixing, and eddy generation, but these mechanisms are uncertain
- **Global coupled wave-ice model** with climate-scale resolution **can simulate local wind waves in partial ice cover**, but more observational constraints are needed

References

Lee et al. (2016). Stratified Ocean Dynamics of the Arctic: Science and Experiment Plan (APL-UW TR 1601). Applied Physic Lab, UW.
Krishfield et al. (2014). Deterioration of perennial sea ice in Beaufort Gyre 2003-2013 and impact on oceanic freshwater. *JGR: Oceans.*
Roach et al. (2019). Advances in Modeling Interactions Between Sea Ice and Ocean Surface Waves. *J. Adv. Model. Earth Systems.*
Collins & Rogers (2017). A source term for wave attenuation by sea ice in WAVEWATCH III®: IC4. Naval Research Laboratory.
Thomson et al. (2013). Waves and the equilibrium range at Ocean Weather Station P. *JGR: Oceans.*
Voermans et al. (2020), Estimating Wind Speed and Direction Using Wave Spectra. *JGR: Oceans.*