Tidal modulation of surface waves in nearshore environments

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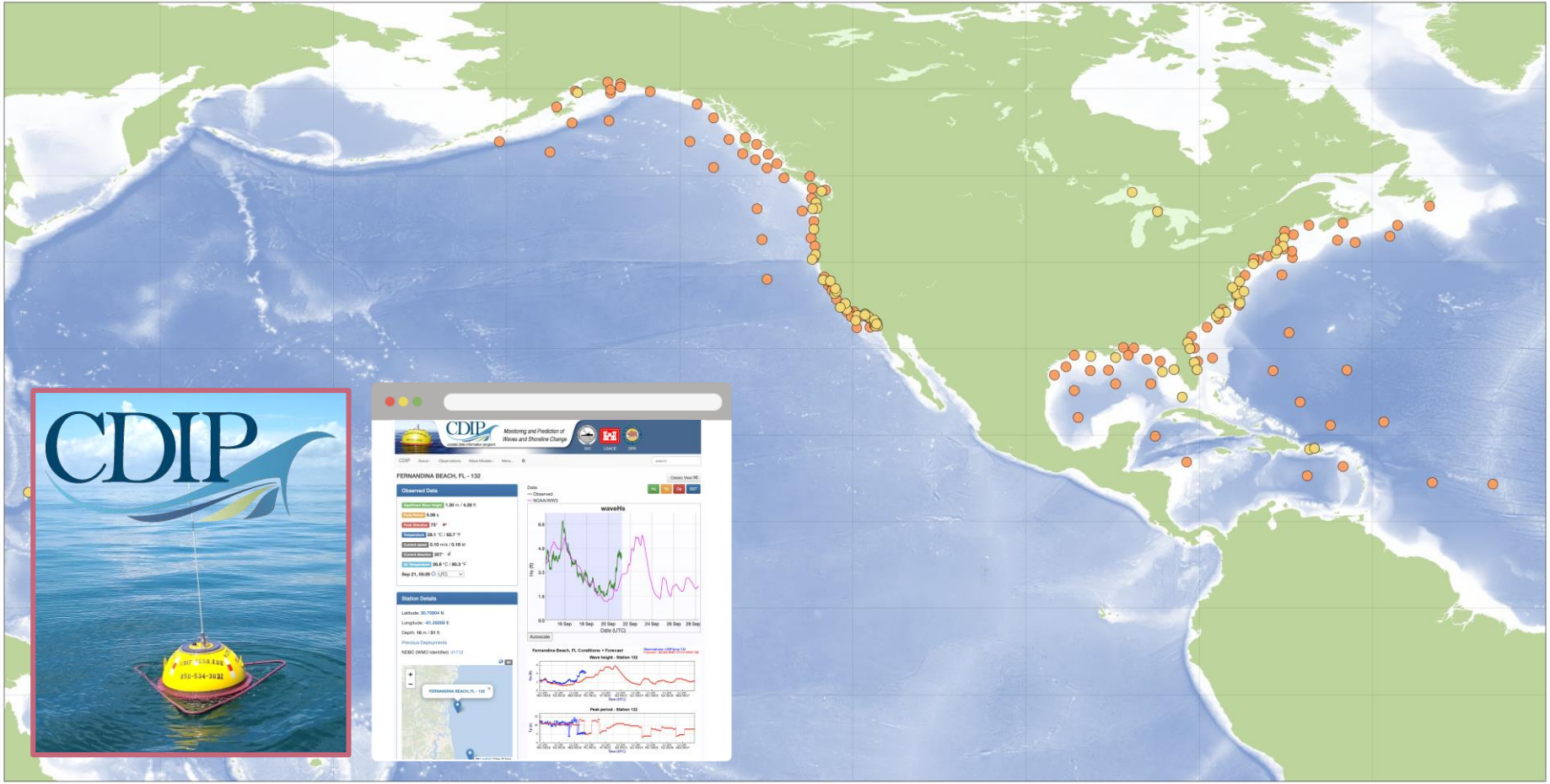
Ho, Merrifield, & Pizzo (2023). Wave-Tide Interaction for a Strongly Modulated Wave Field, *Journal of Physical Oceanography*. https://doi.org/10.1175/JPO-D-22-0166.1

In-situ observations of ocean waves



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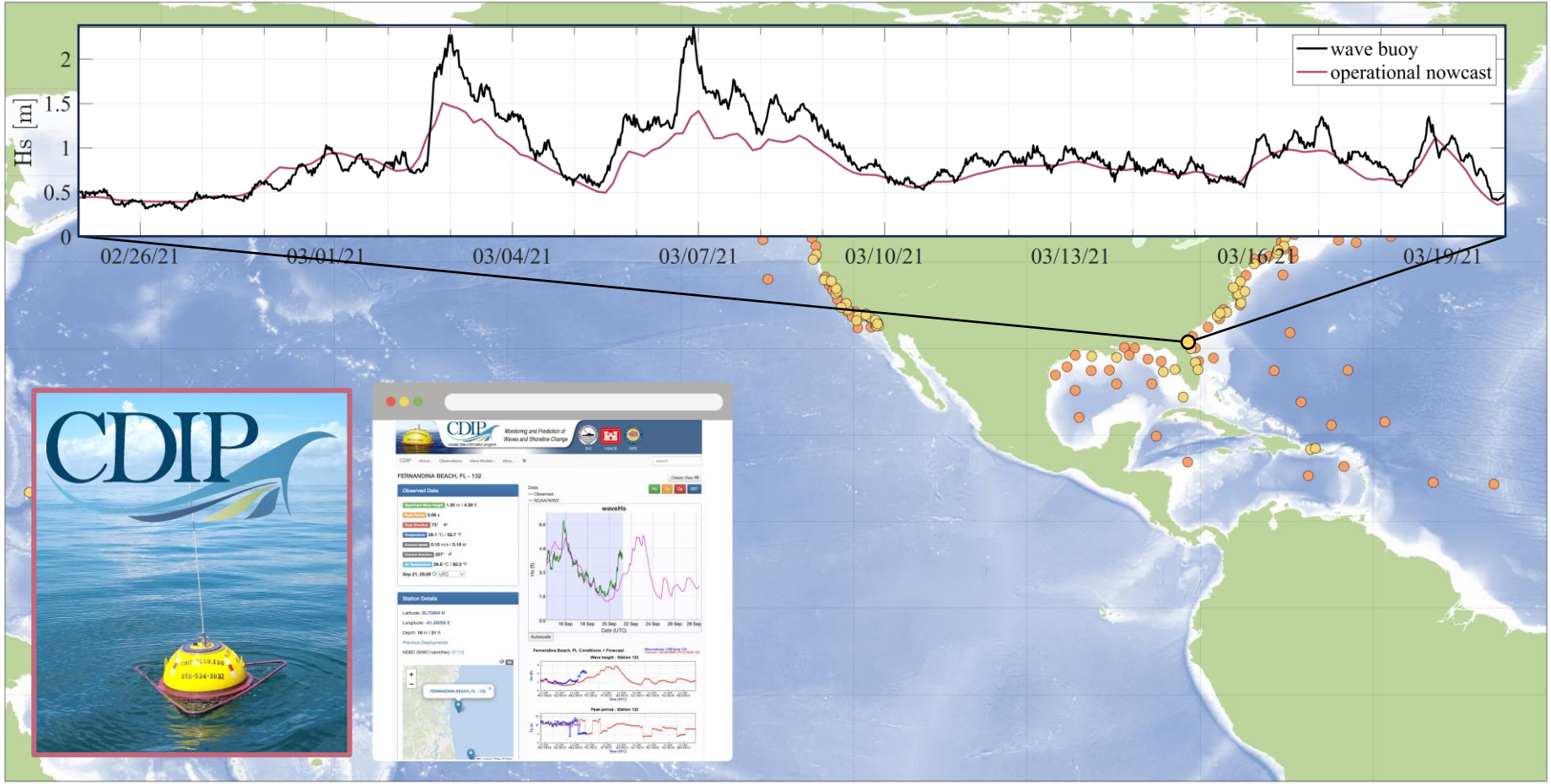
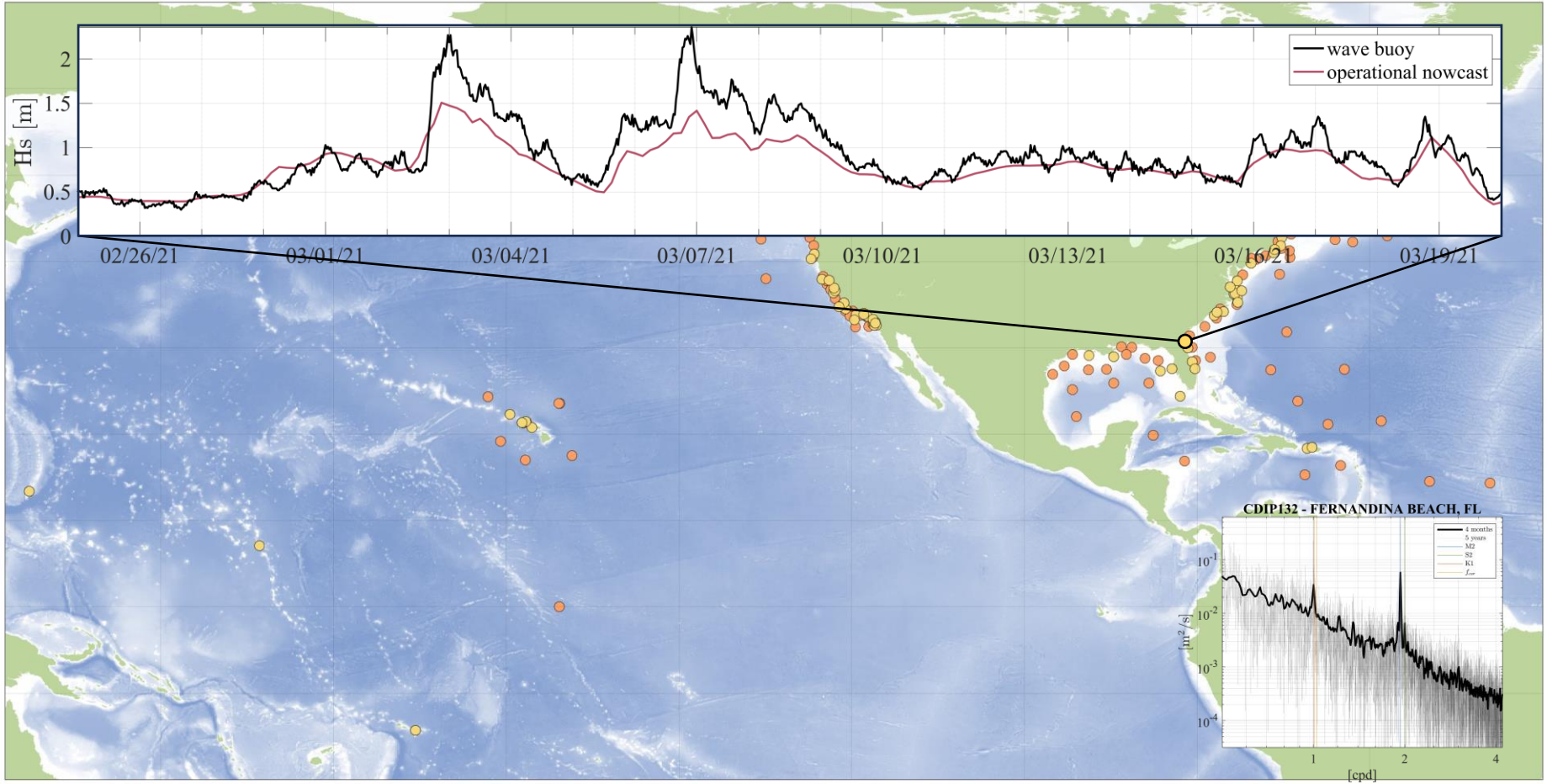


Tidal signatures in wave records



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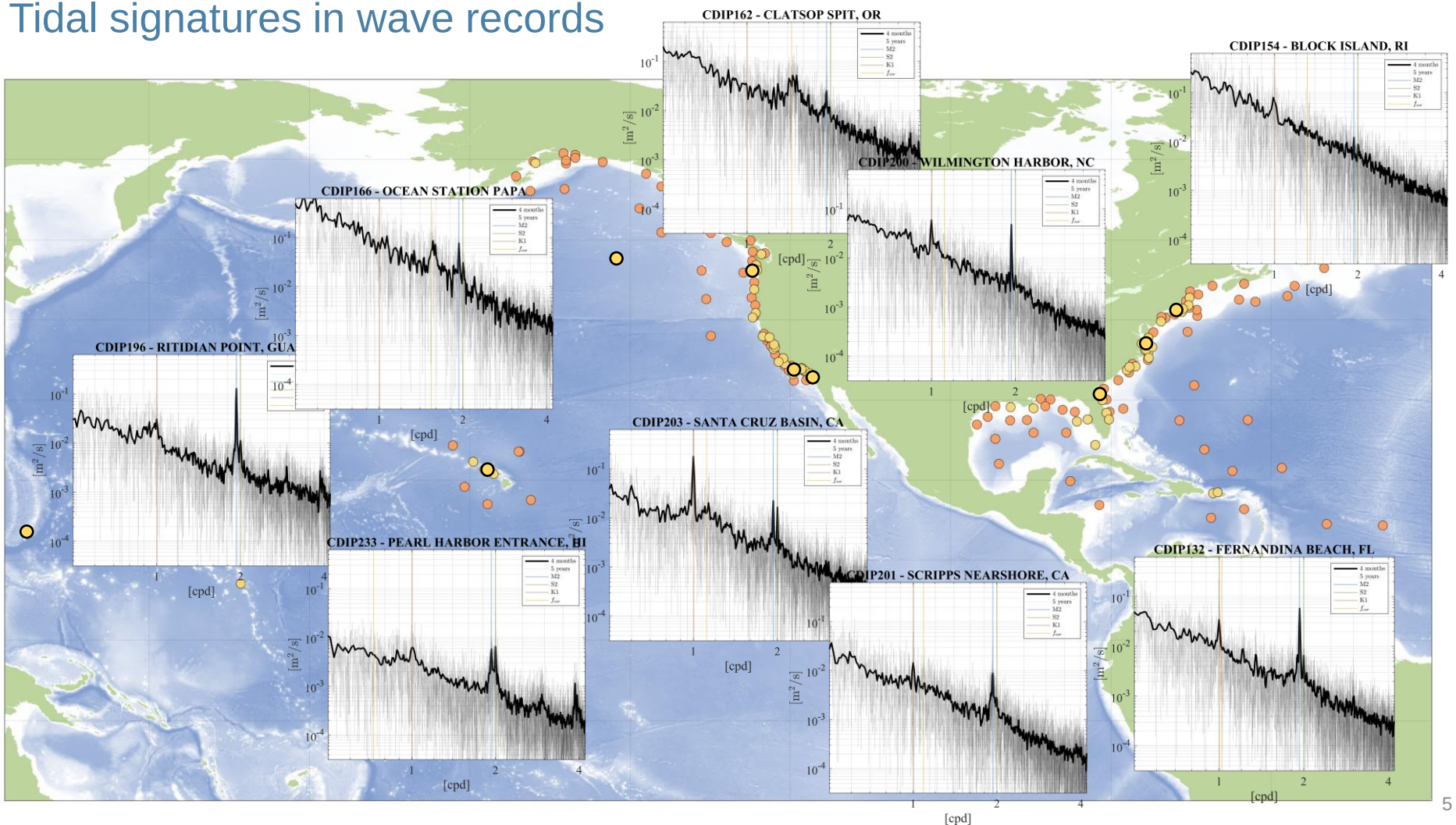
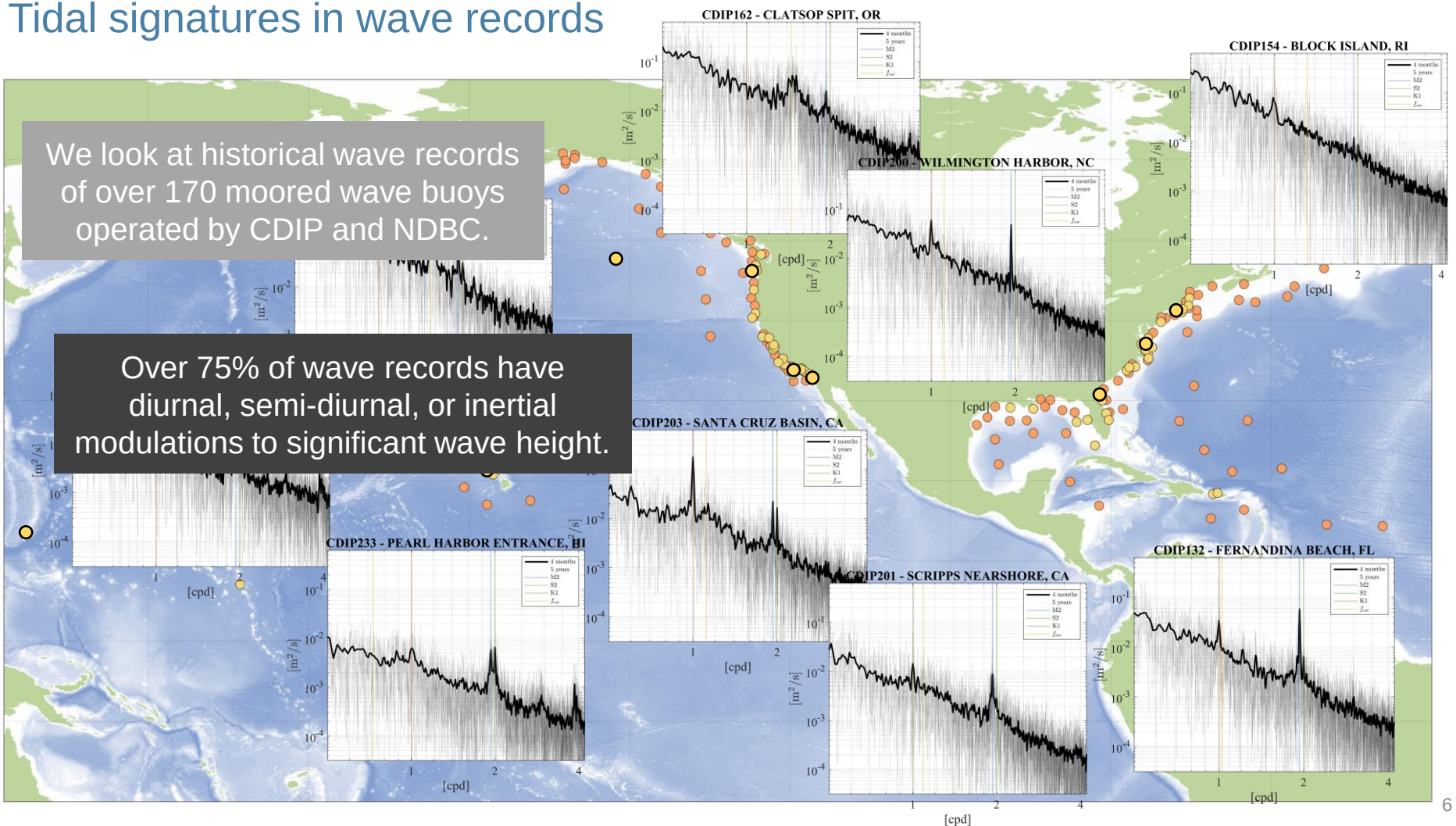


Tidal signatures in wave records

We look at historical wave records of over 170 moored wave buoys operated by CDIP and NDBC.

Over 75% of wave records have diurnal, semi-diurnal, or inertial modulations to significant wave height.



Overview

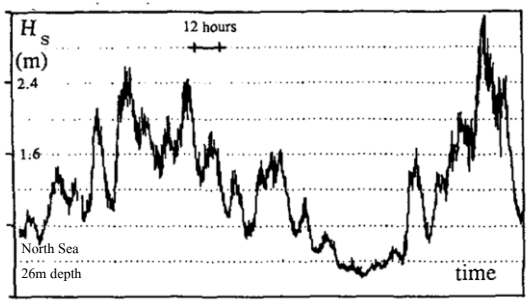
Modulation in wave records related to inertial currents, diurnal winds, and tides are observed in buoys across the US coasts.

Wave-tide interactions can strongly influence the observed nearshore surface wave variability but is often not resolved in operational wave forecasts.

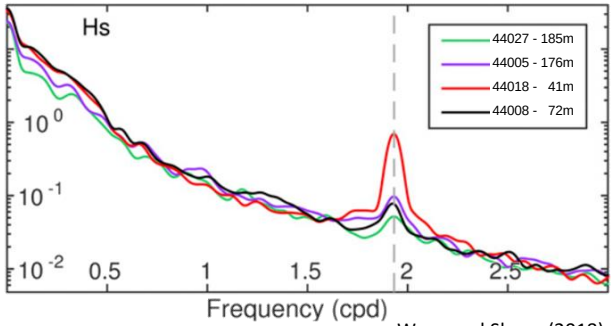
The interaction between waves and tide is characterized in a case study at Fernandina Beach, FL to demonstrate how the modulation can be explained by assuming the tide modulates the surface waves through a long-wave short-wave interaction.

How do tides impact surface waves?

- Observations of tidal variations in surface waves up to 50% in deep water and coastal environments.

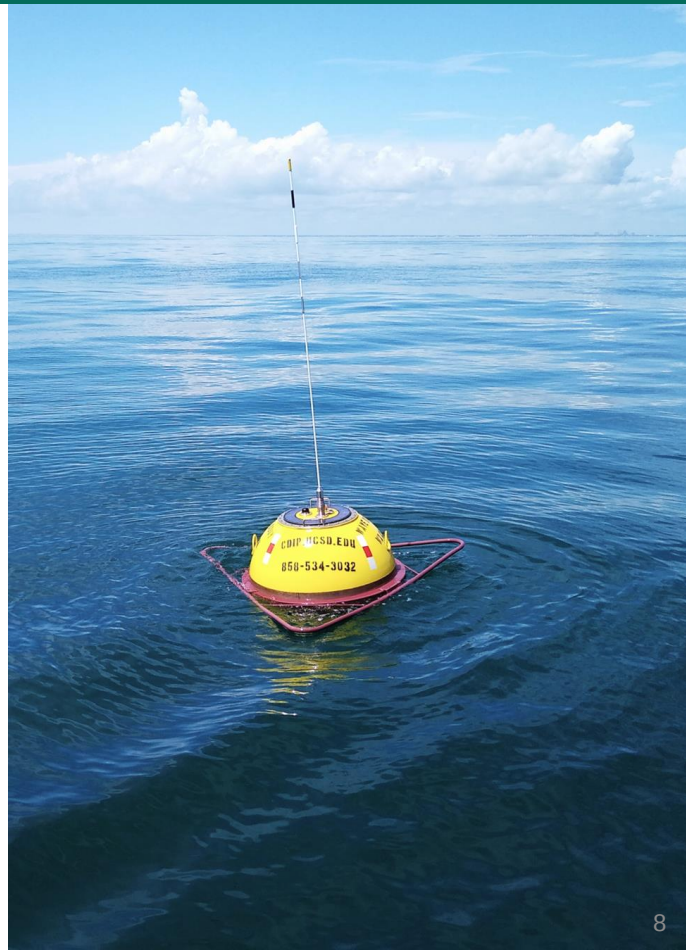


Tolman (1990)

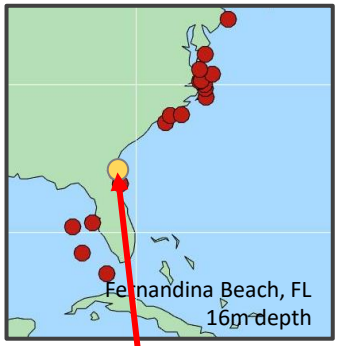


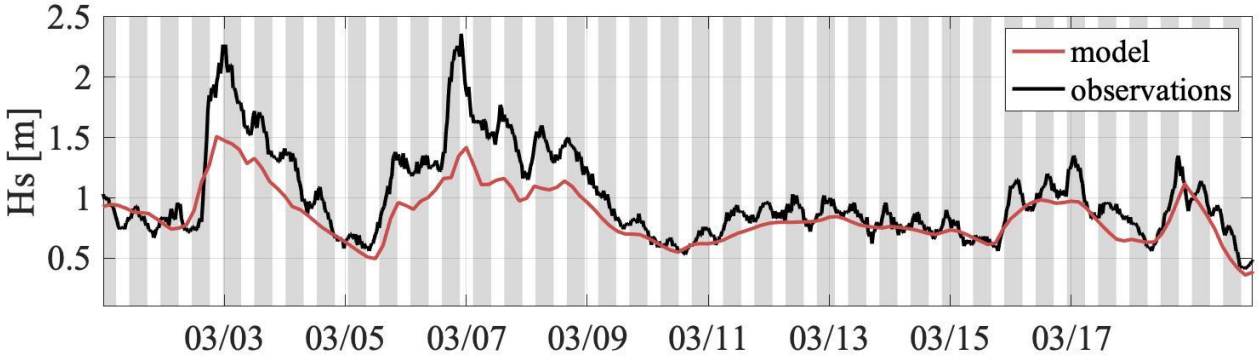
Wang and Sheng (2018)

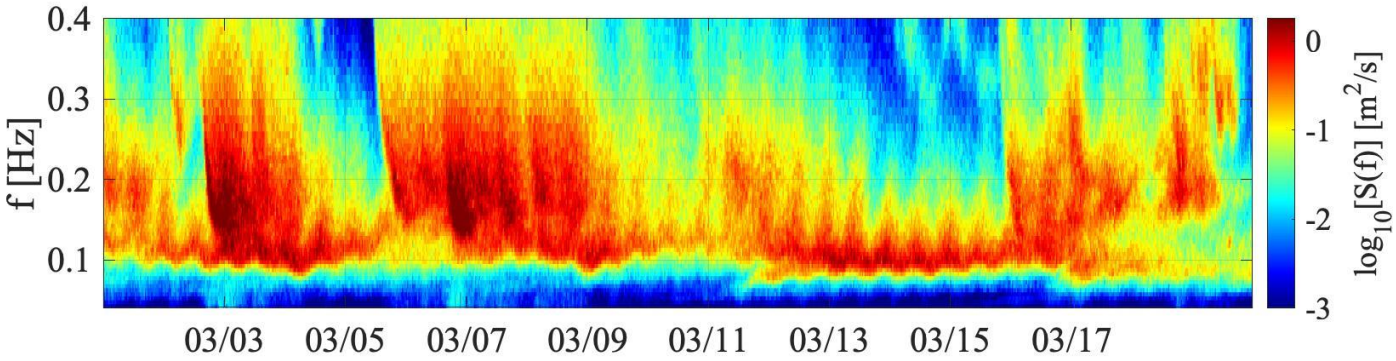
- Observations have shown wave heights increase on both following and opposing tidal currents. (e.g. Davidson 2008, Gemmrich and Garrett 2012, Wang & Sheng 2018).



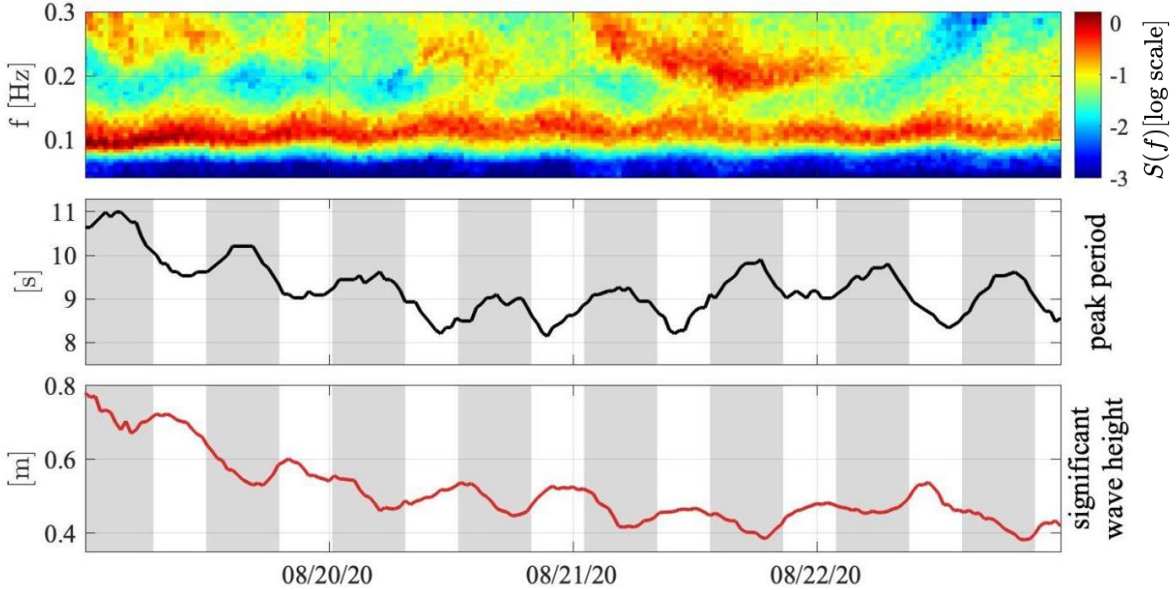
Case study: Observations of significant tidal modulation at Fernandina Beach, FL.



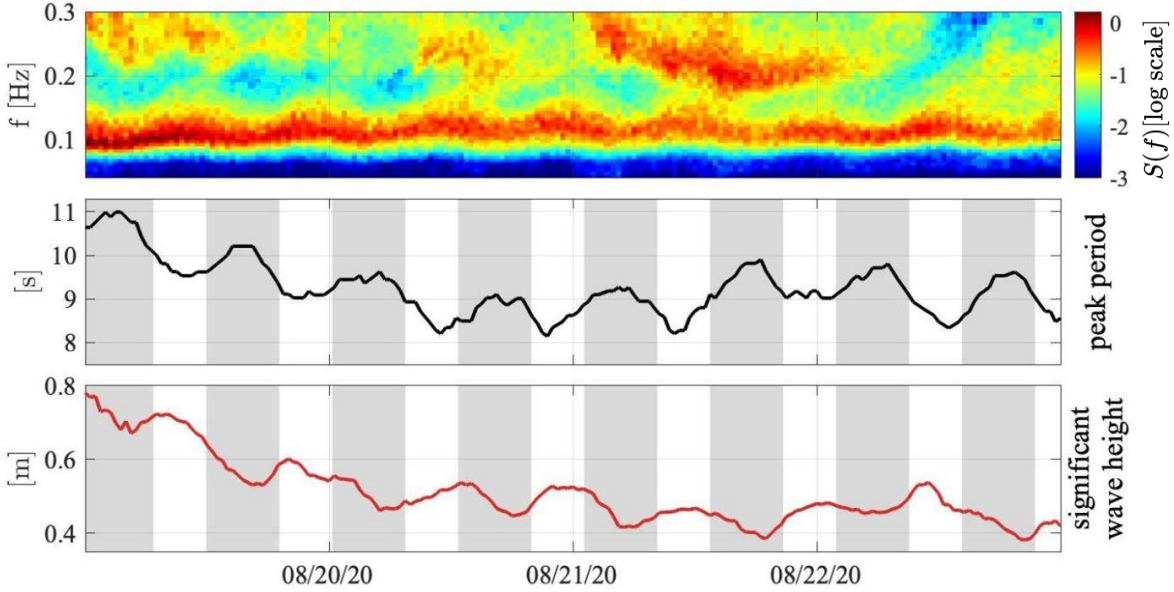


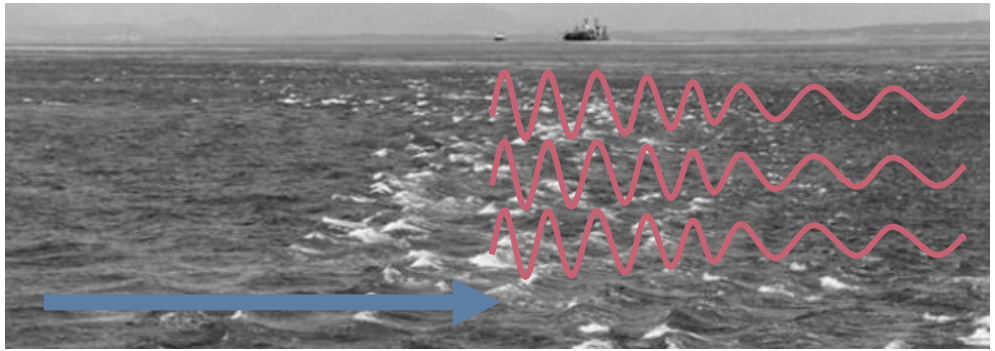


Oscillation near peak of the spectra & periodic change in wave steepness

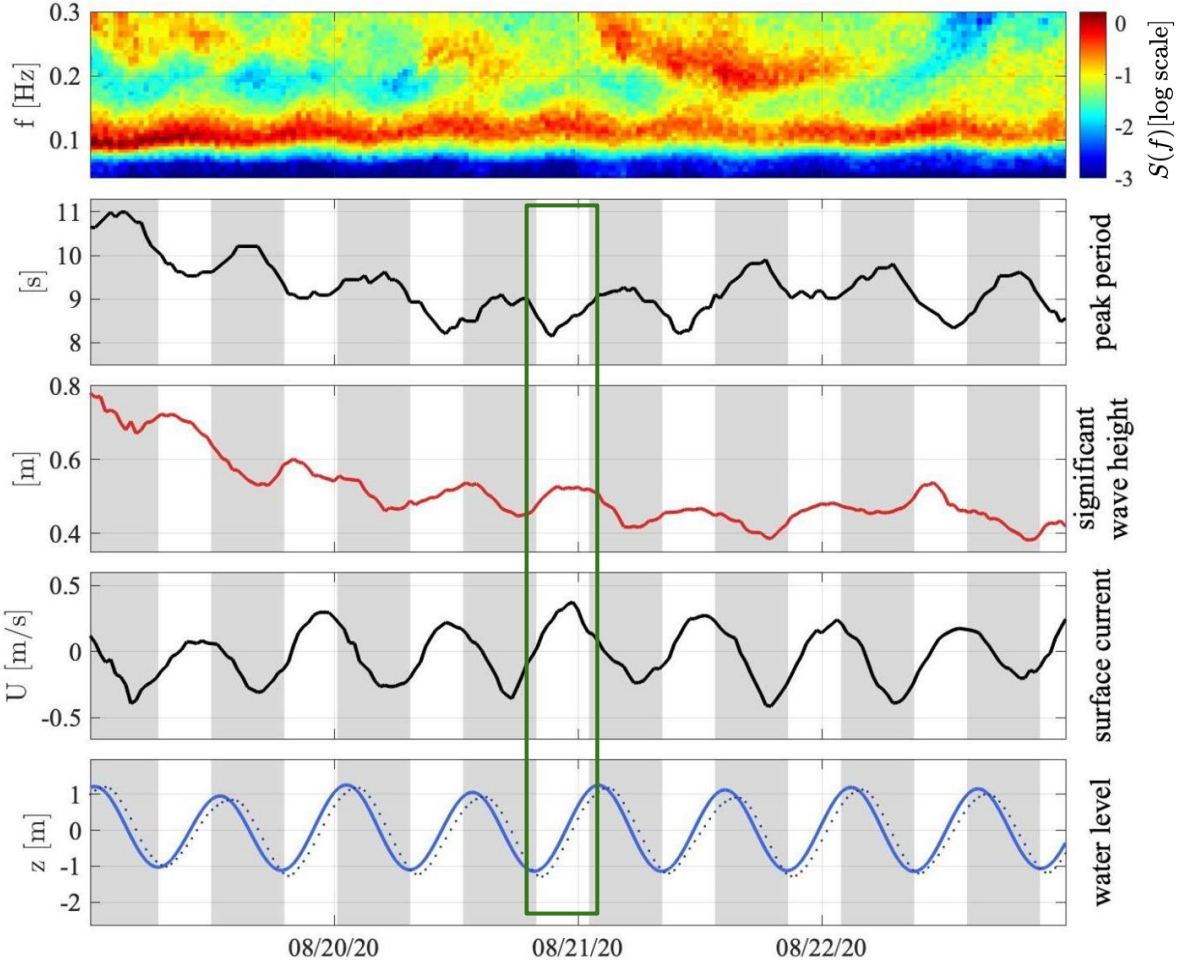


Periodic change in wave steepness

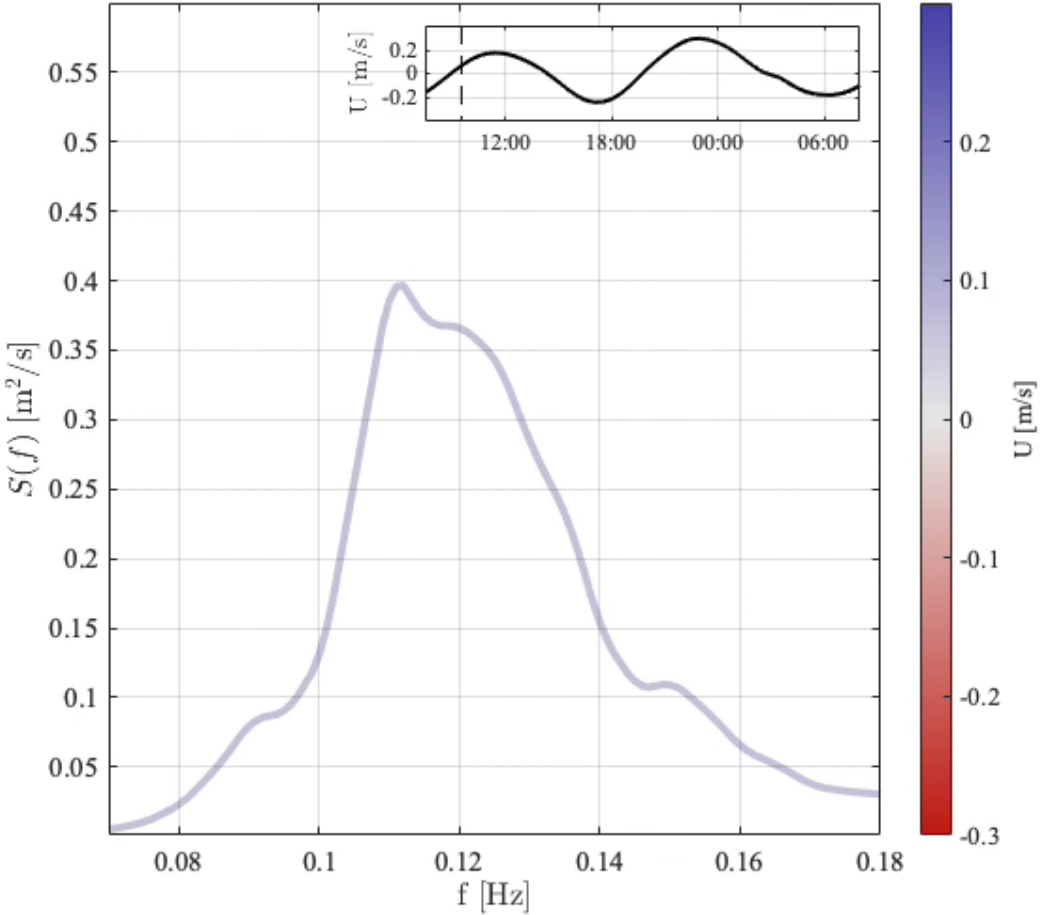




On opposing currents, waves decrease amplitude and increase period



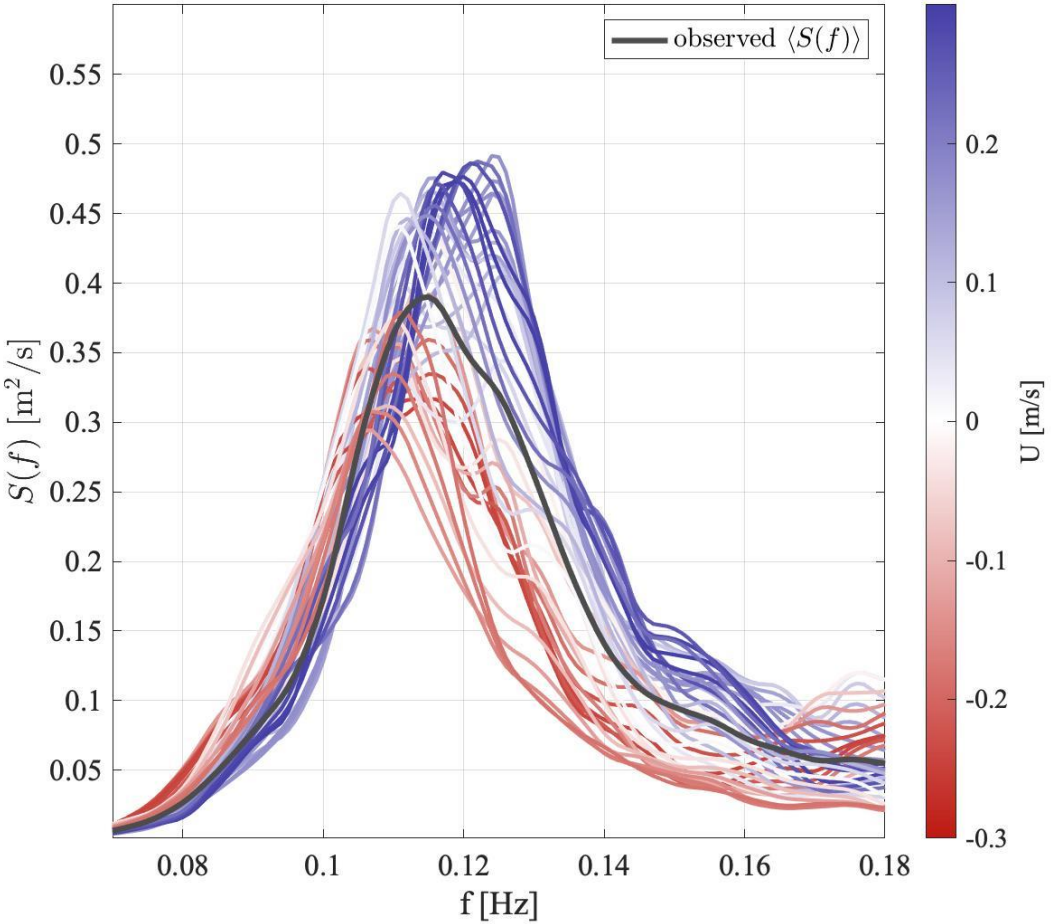
On opposing currents, spectra shifts to lower frequency and energy



Current following wave direction

Current opposing wave direction

On opposing currents, spectra shifts to lower frequency and energy



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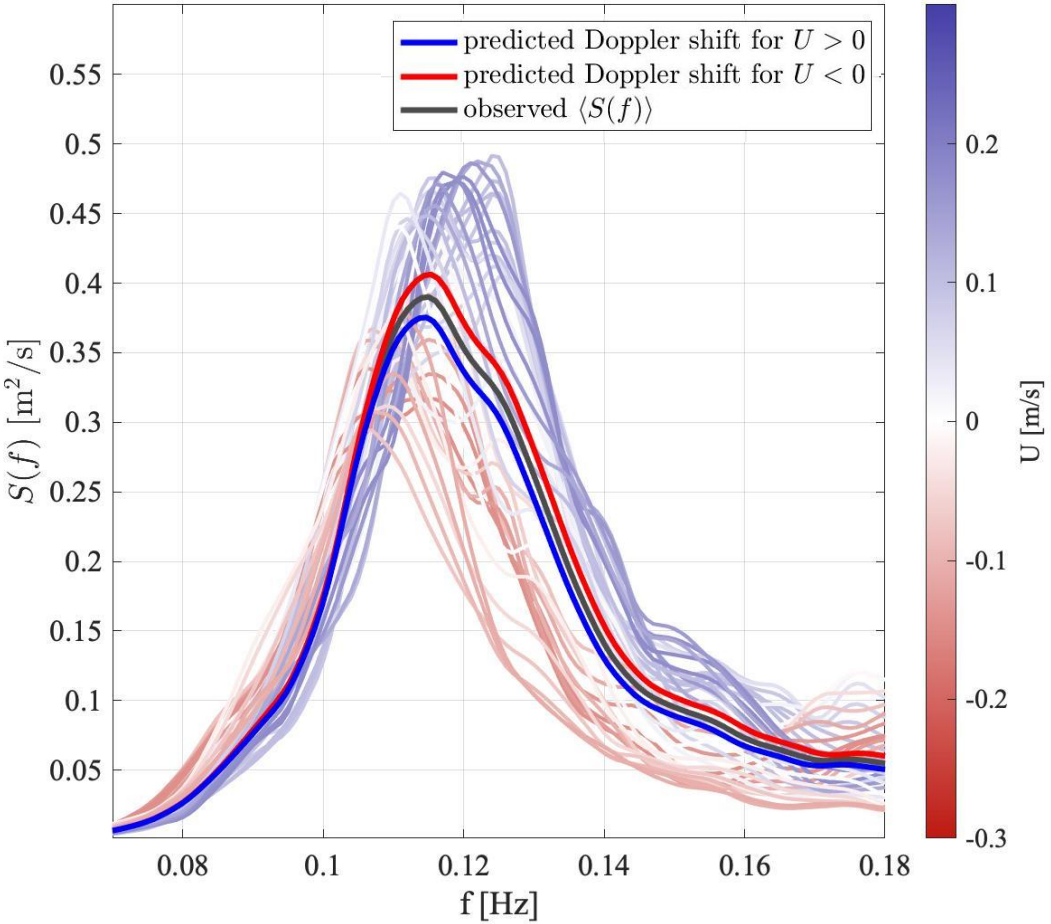


Current following wave direction

Current opposing wave direction

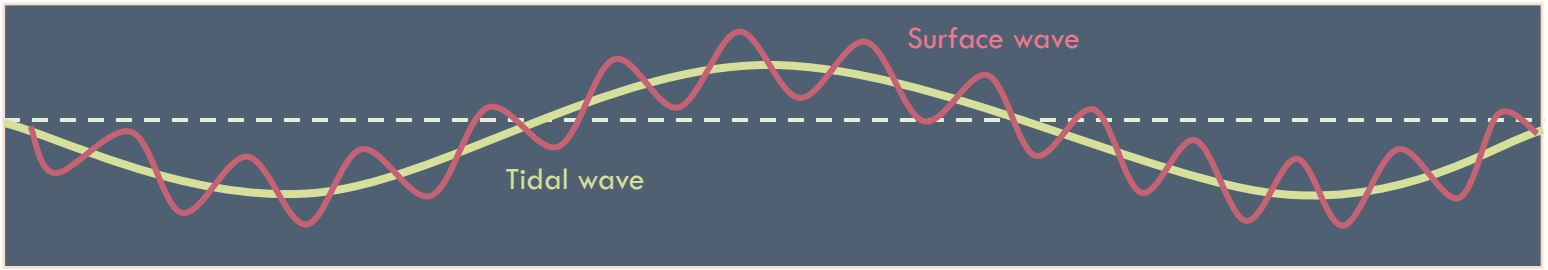
1. How does the wave amplitude change as a function of the phase of the tide?
2. Which frequencies are most affected?
3. Do directional effects matter?

Resolve complexity and IRL behavior, higher computational costs

Simplified idealized solutions to build intuition

Simplify to interaction between tidal wave and surface wave

We use simplified analytical and numerical solutions to the equations of geometrical optics and conservation of wave action under the assumption of a tide acting as a progressive monochromatic shallow water wave – accounts for both the temporal and spatial variation of the tidal forcing terms, and effectively treats the problem as a **long-wave short-wave interaction**.



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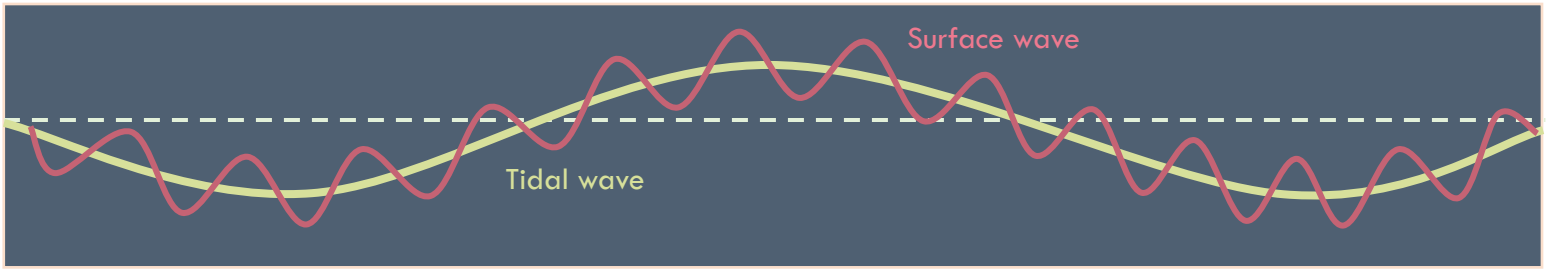
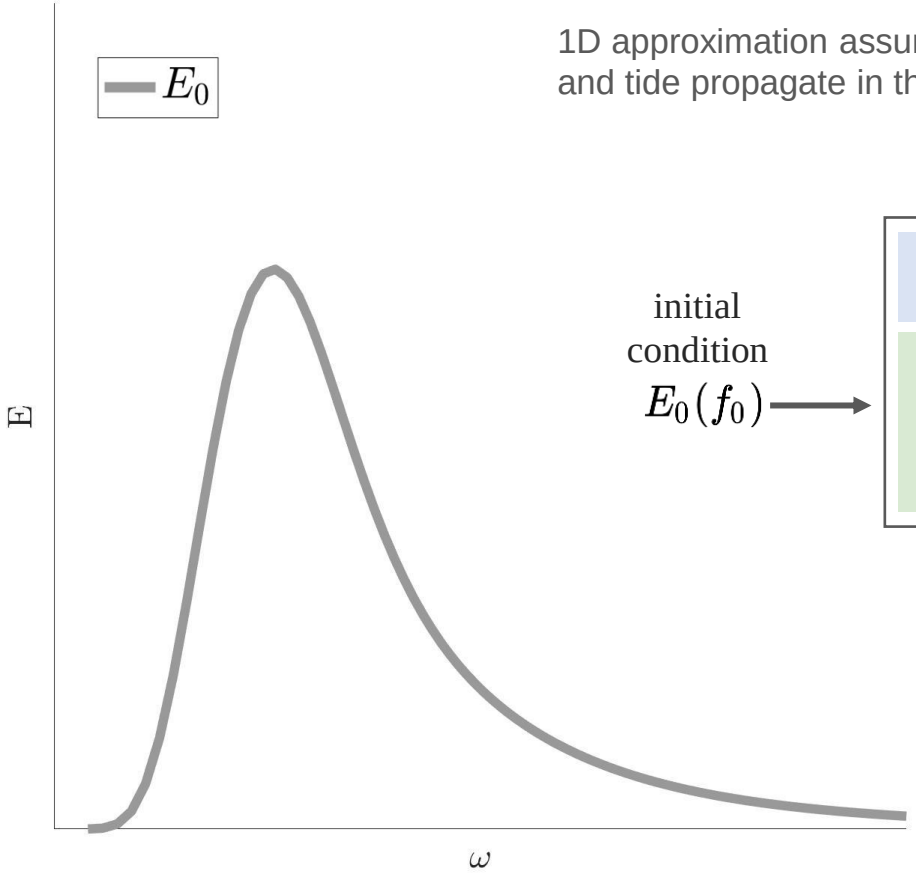


We find that surface waves will be amplified by the tide:

- ❑ *When A_u or A_h is **relatively** large*
- ❑ *When surface waves propagate in the direction of the tidal currents*
- ❑ *When the speed of surface waves propagation nears the speed of the tidal wave*

Solutions to the simplified model



1D approximation assuming that the currents, waves, and tide propagate in the **same direction**

initial condition $E_0(f_0)$ →

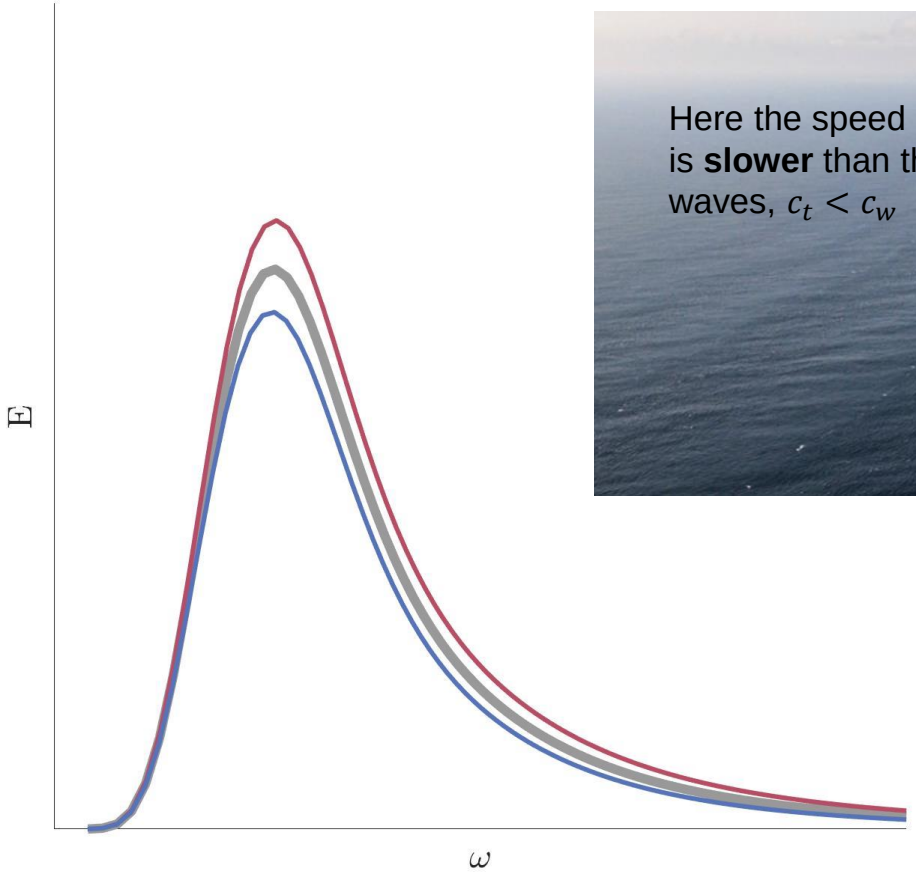
long wave c_t

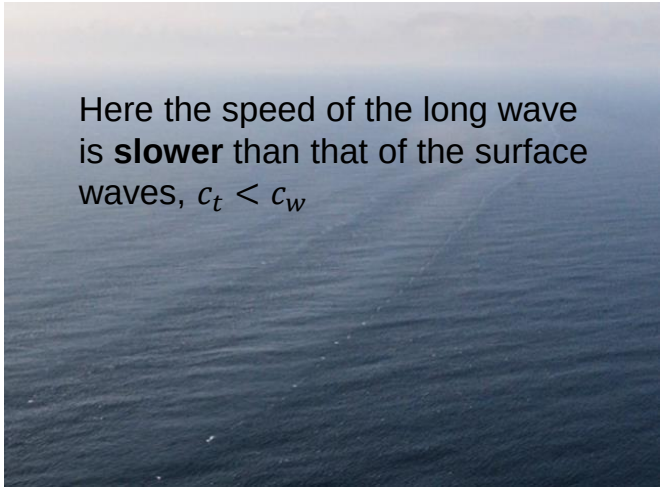
forcing $U(x,t)$ $h(x,t)$

→ shifted spectrum $E(f)$

Solutions to the simplified model: long wave is slow / non-existent

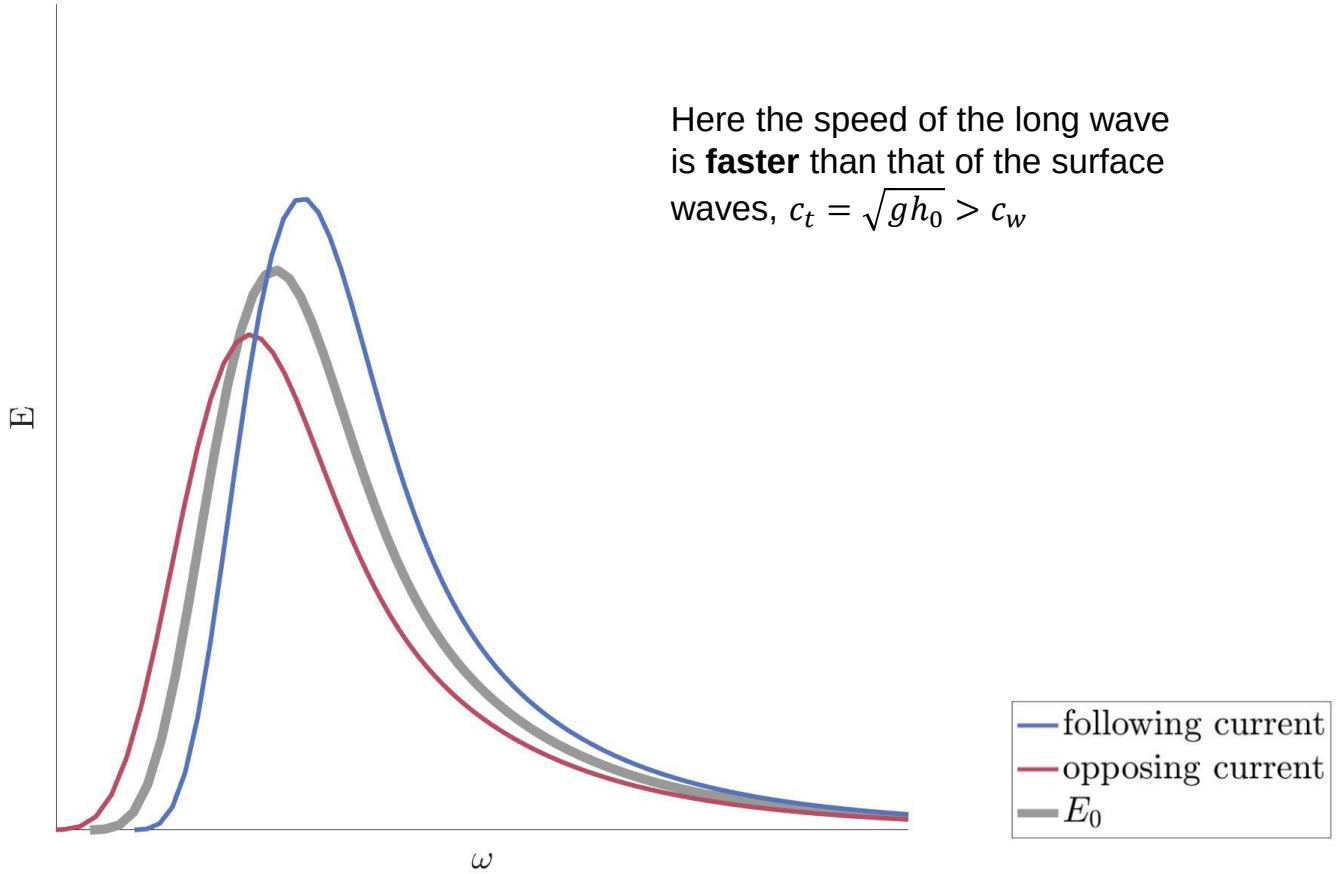
Reproduce behavior expected from Doppler shifting or internal waves.





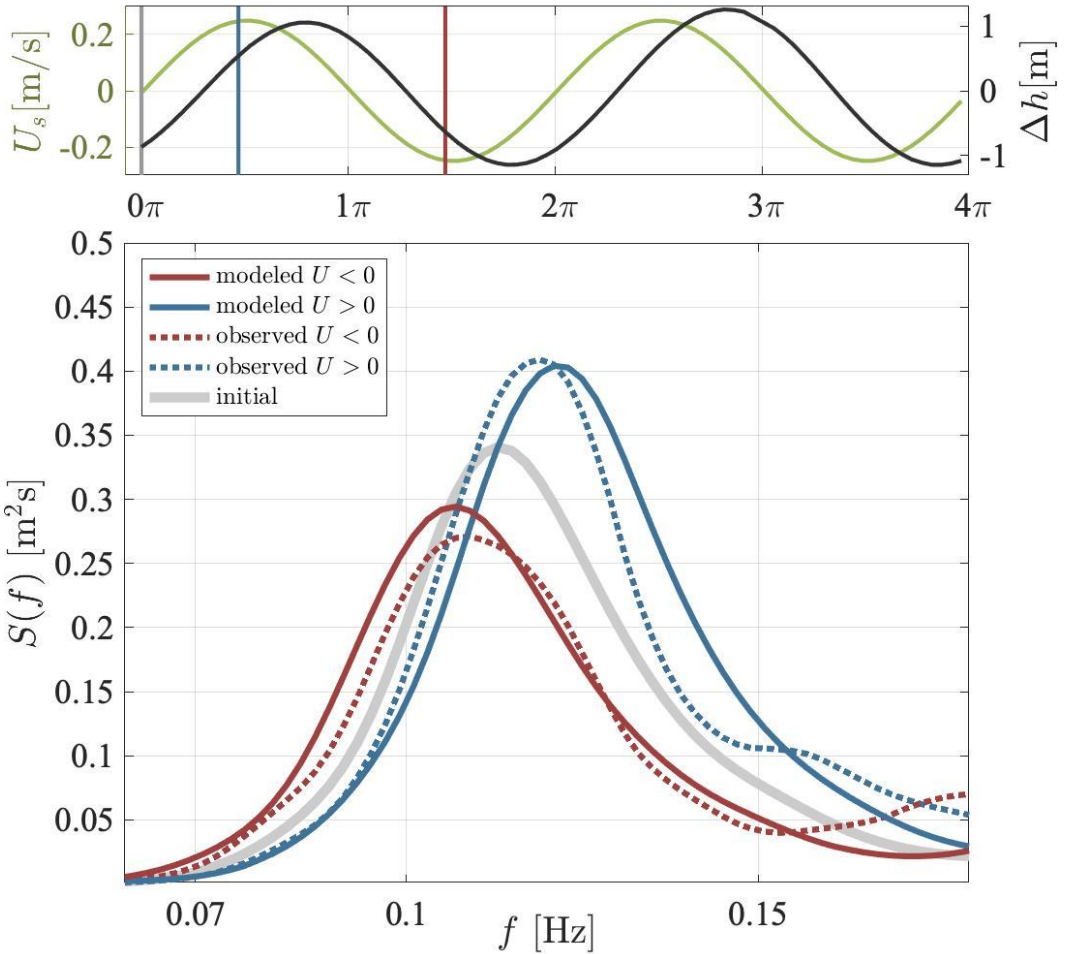
Solutions to the simplified model: long wave is now the tide

Reproduce behavior observed at Fernandina



Here the speed of the long wave is **faster** than that of the surface waves, $c_t = \sqrt{gh_0} > c_w$

Solutions to the simplified model: direct comparison to observations



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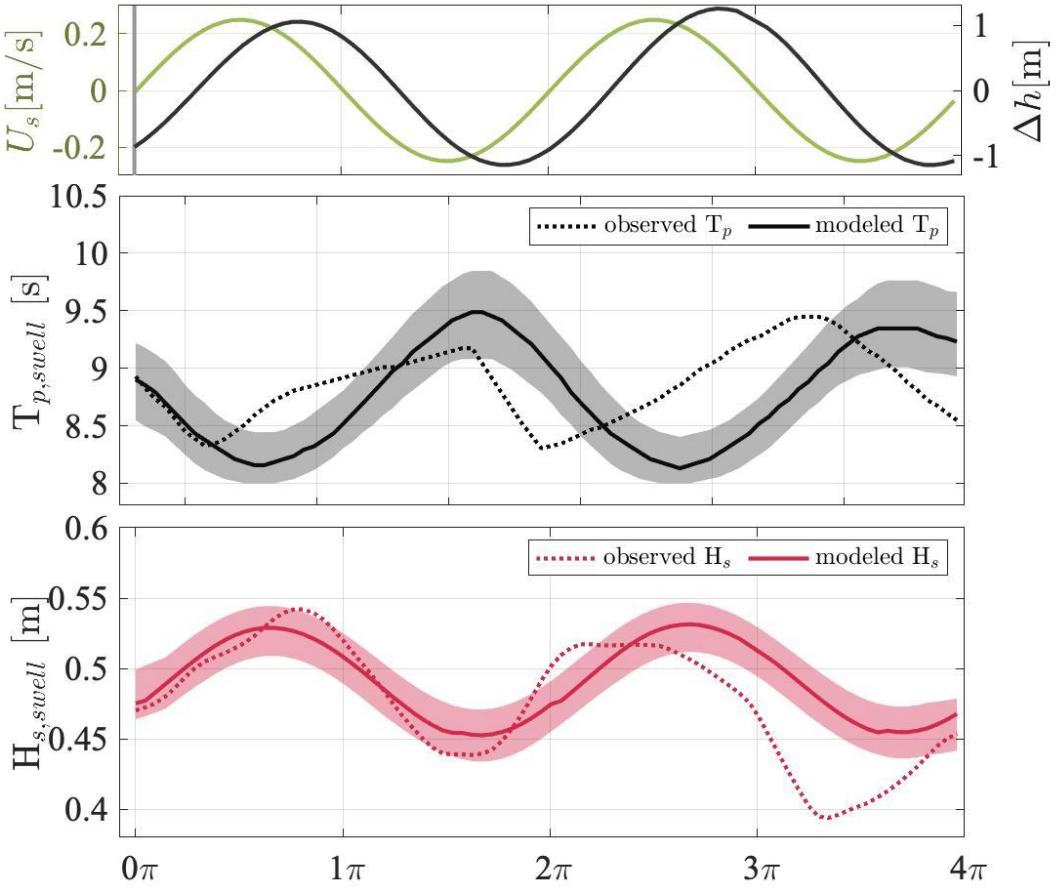
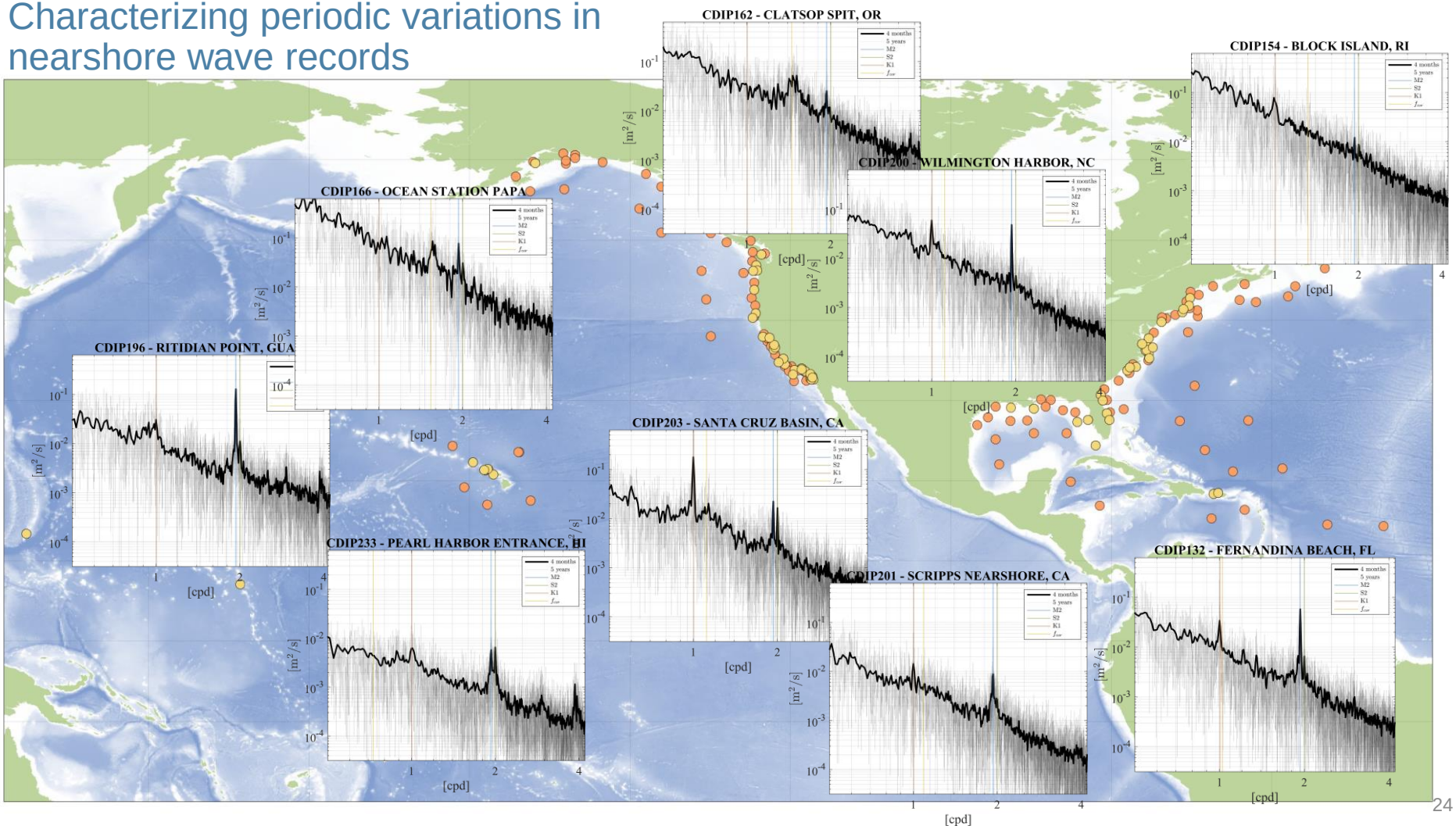


Characterizing periodic variations in nearshore wave records



Summary

This work uses a simplified idealized model to explains surface wave tidal modulation in a nearshore environment through long-wave short-wave interaction to

- *estimate change in omnidirectional wave spectra due to tide,*
- *predict observed tidal variations in bulk parameters and higher order moments at Fernandina Beach.*

We seek to further characterize the tidal variability in wave records in US coastal waters and explore deviations from the simplistic model under complex tidal and wave climates.

Ho, Merrifield, & Pizzo (2023). Wave-Tide Interaction for a Strongly Modulated Wave Field, *Journal of Physical Oceanography*. https://doi.org/10.1175/JPO-D-22-0166.1

Ho et al. (in prep). Characterizing tidal modulations in nearshore wave records.

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