Wave Period and Energy Variability of Surface Gravity Waves in the Upper-Chesapeake Bay

Midshipman 1/C Garrison T. Clark, Midshipman 1/C David W. Moore, and Midshipman 1/C Nataline R. Ziola, USN, Class of 2023

Advisors: CAPT Shawn Gallaher, Instructor Alex Davies, Mr. Ben Hickman, and Instructor Brianna Tracy; Ocean and Atmospheric Sciences Department, U.S. Naval Academy, Annapolis, MD USA

ABSTRACT

This project analyzes the relationship between meteorological conditions and the wave energy field of the Upper Chesapeake Bay and Severn River. This project found that southeast winds generate the largest fetch conditions and the greatest wave energy in the Upper Chesapeake. The wave field is dominated by wind waves ranging from 1.8 s to 4 s periods with correlating frequencies of 0.55 Hz to 0.25 Hz. Significant wave heights were found to increase as wave energy intensified. Additionally, the Upper Chesapeake was concluded to be a fetch limited environment in where a fully developed sea can be realized in as little as 2-4 hours during intense local and synoptic scale wind events.

STUDY AREA & METHODS

Figure 1. Locations of sensor deployment at Hackett Point and Annapolis Anchorage within the Upper Chesapeake Bay study area (left); Deployment of the RBR pressure sensor at Hackett Point (right).

SOFAR Spotter buoys and RBR pressure sensors were deployed at two different locations in the Chesapeake Bay to evaluate variability of wave energy and frequency across different fetch orientations. The two study areas selected were the anchorage outside Annapolis Harbor and Hackett Point near the Bay Bridge **(Figure 1)**. Data collection were conducted from 26 January to 7 March. The SOFAR buoys were deployed at the surface and RBR sensors were deployed via cement moorings at approximately 3 meter water depth in the same vicinity (**Figure 2**). Deployment depth was chosen in order to mitigate dampening of the dynamic pressure data and to ensure the observation of primarily deep water waves. SOFAR Spotter buoys sampled at a frequency of 1 Hz and RBR pressure sensors sampled at 4 Hz. The team was able to collect wave data at the surface and at depth with this configuration.

Thirty minute time periods from collected RBR pressure sensor data were selected after comparing the SOFAR real-time data to the RBR time series. Specific periods were imported as column vectors in MATLAB and used to create pressure vs. time figures. Pressure data was detrended in preparation for transformation into power density spectra (PDS) and re-amplified to correct for dynamic pressure dampening per linear wave theory. Previous Capstone work defining spectral corrections required to account for attenuation of submerged pressure sensors were achieved by (Gibbons et al., 2005):

$$A(f,z) = \frac{\cosh\big(k(h-z)\big)}{\cosh(kh)} \quad (1) \qquad k = \frac{\left(\frac{1}{1.5T}\right)^2}{g} \quad (2)$$

The variable could then be examined on the PDS to identify where an amplification of 99.5% of the data was needed by calculating attenuation . The amplification factor was unique for each case study and applied to the PDS

Figure 2. Left to right. SOFAR Spotter wave buoy used to collect surface wave, wind, temperature, and barometric pressure data; RBR pressure sensor used to record pressure readings at 3 meters depth; mooring made of cement base and pipe stem for RBR pressure sensor attachment.

RESULTS

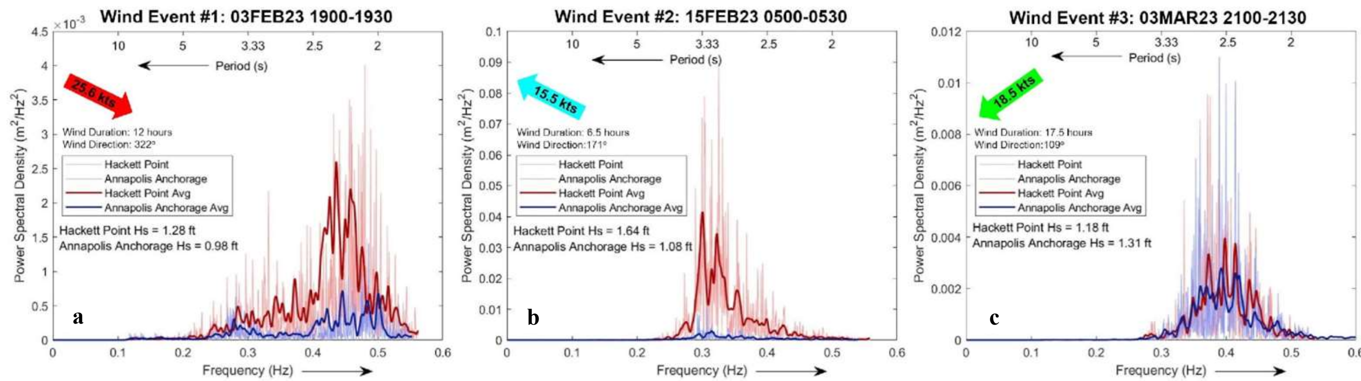

Figure 3. Power density spectra for (a) Wind Event 1 on 03 February 2023 from 1900-1930, winds at this time were coming from the northwest , denoted by the red arrow, and produced 1.8 s up to 4 s period waves; (b) Wind Event 2 on 15 February 2023 from 0500-0530, winds at this time were coming from the southeast, denoted by the cyan arrow, and produced 2.2 s to 3.5 s period waves; (c) for Wind Event 3 on 03 March 2023 from 2100-2130, winds at this time were coming from the northeast, denoted by the green arrow, and produced 2 s to 3.3 s period waves.

Figure 4. Fetch distances calculated for each wind event for both Annapolis Anchorage and Hackett Point using Google Earth Pro. A southeast wind and a northeast wind display a larger fetch distance at Hackett Point. In opposition, a northeast wind displays a greater fetch distance at Annapolis Anchorage.

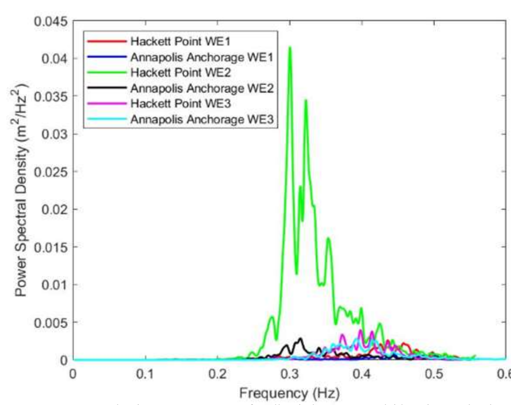

Figure 5. Power density spectra averages for all Wind Events overlaid against each other. Wind Event 2, a Southeast wind, displayed the most energy at Hackett Point. The majority of the wave energy is focused from 0.25 Hz to 0.55 Hz.

Fetch distance and energy were greater at Hackett Point as compared to Annapolis Anchorage, measuring a maximum of 4 x 10^{-3} m^2/Hz^2 at Hackett Point and 1.5 x 10^{-3} m^2/Hz^2 at Annapolis Anchorage for Wind Event #1 (**Figure 3a**). Wind Event #2 followed the same trend, measuring 0.09 m^2/Hz^2 at Hackett Point and 0.01 m^2/Hz^2 at Annapolis Anchorage (**Figure 3b**). Hackett Point had a slightly larger significant wave height than Annapolis Anchorage in both Wind Event #1 and #2. Wind Event #3 displayed similar energy spectra for both locations (**Figure 3c**). Annapolis Anchorage did display greater maximum wave energy than Hackett Point, however, there was only a small difference between the two with Annapolis Anchorage reaching 0.011 m^2/Hz^2 and Hackett Point reaching 0.01 m^2/Hz^2 (**Figure 3c**). Wind Event #2 had the longest fetch distance and greatest wave energy (**Figure 4 and 5**). Wave heights at Hackett Point during Wind Event #2 were observed at 2.2 feet which correspond well with theoretical wave estimates from the Brettschneider nomogram based on available fetch, wind intensity, and wind duration (**Figure 6**). In-situ significant wave height for the same location and event was 1.64 feet recorded using the SOFAR buoy. This provided a validation that the data collected was accurate.

DISCUSSION

There were no further changes to wave height past 4 hours based on the nomogram, although Wind Event #2 lasted 6.5 hours. Thus, the Upper Chesapeake is a fetch limited environment in which the fully developed sea is realized within 2 to 4 hours of a wind event. This southeast wind event also had the greatest wave energy. Additionally, the three case studies show that greater fetch distances correlates to increased wave energy. The location with the larger fetch distance displayed greater significant wave heights indicating that as wave energy increases, significant wave height increases in each of the three events.

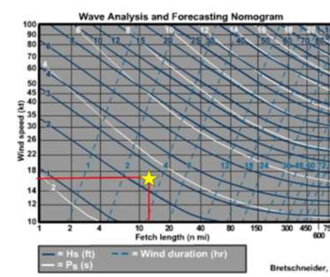

Figure 6. Nomogram used to calculate wave height based on wind duration, speed, and fetch length. Yellow star indicates Wind Event #2 at Hackett Point.

CONCLUSIONS & FUTURE WORK

- ***The Chesapeake Bay is a fetch-limited environment where southeast winds generate the largest fetch and energy.***
- ***The wave field of the study locations is dominated by 1.8 s to 4 s moderate-to-high frequency wind waves with significant wave height increases with higher power spectral densities.***
- ***Future work should examine wave power density spectra from other wind directions not investigated in this study; or, further up the Severn River or South River areas.***

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