CHARACTERIZING TRAILING WAVES FROM CARGO SHIP WAKE

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INTRODUCTION

Low-frequency (LF) cargo ship wake is a major source of hydrodynamic energy in shipping channels, where it has increasingly been linked to shoreline erosion. The LF wake consists of a drawdown called the "Bernoulli depression," a return surge, and finally a series of trailing waves that may persist longer than 30 minutes after the vessel passage (Figure 1). While the Bernoulli depression and surge are well-explained by conservation principles, we presently lack a robust explanation of the trailing waves. They are a ubiquitous feature observed at many locations (e.g. Garrel, Lopez, and Collins, 2008), and have frequently been attributed to cross-channel seiching; however, field measurements from the Savannah River, GA, USA suggested that some of the waves may have alongshore progressive characteristics, which contradicts this assumption.

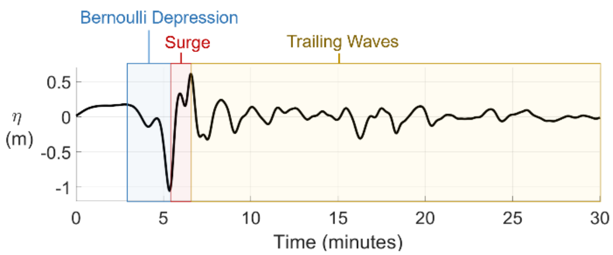

Figure 1 - A sample field measurement of low-frequency cargo ship wake showing the Bernoulli depression, surge, and trailing waves.

Over 500 large vessel wake events were measured with current profilers and pressure transducers in a previous study investigating the source of erosion at Bird/Long Island in the Savannah River, Georgia, USA (Haas and Muscalus, 2019). The island divides the river into two channels, the larger of which - the "Main Channel" - contains a shipping channel with about 5,000 annual cargo ship transits. Measurements on the shelf of the Main Channel along Bird/Long Island revealed that the low-frequency (LF) component of vessel wake is the dominant energy source; its contribution is much stronger than that of tidal currents, wind waves, and Kelvin waves. While the primary wave is the most energetic wave in the LF wake system, the trailing wave system contains on average 40% of the total LF wake energy. Therefore, it is imperative to gain a better understanding of trailing wave characteristics and their generation mechanisms.

CHARACTERIZING TRAILING WAVES IN THE FIELD

In order to characterize the trailing waves, two different field experiments with alongshore arrays of pressure transducers were completed. Within the Savannah River along Bird/Long Island, an alongshore array spanning 290 m with seven variably spaced instruments was deployed in approximately 3 m mean water depth in February 2022, and an alongshore array spanning 240 m with six variably spaced instruments was deployed in a little over 2 m mean depth for several days each (Figure 2). In addition, the channel bathymetry was surveyed along the full island. In February, 37 cargo ship passages and in June 42 cargo ship passages were captured with both inbound and outbound vessels. Figure 3 below shows the occurrence rate of the speed and length of the vessels for the two time periods. Both months had vessels with similar lengths ranging from 100 to 400 m long; however, the February data set had more vessels traversing the channel at higher speeds. While a range of vessel speeds were observed, from 4.5 to over 8 m/s, all depth Froude numbers for the vessels remained well within the subcritical range.

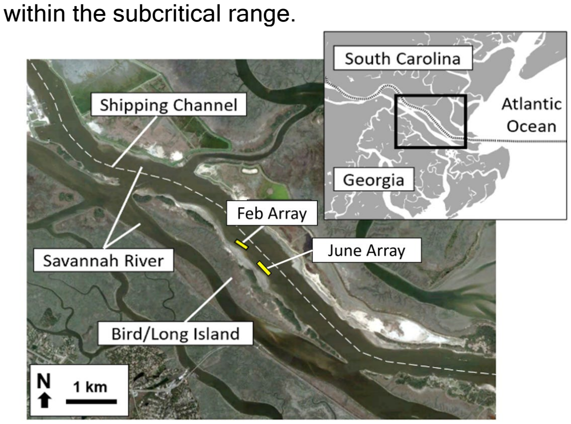

Figure 2 - Map of the location for the seven-instrument (Feb) and six-instrument (June) alongshore arrays near Bird/Long Island in the Savannah River, Georgia, USA.

Figure 4 shows an example time series from an outbound vessel (Cosco Excellence) on June 9, 2022. The 366 m long vessel was traveling approximately 6 m/s when it passed the longshore array around 22:35. The first wave is the Bernoulli depression which is attached to the passing vessel. This event had a large depression around 0.9 m. The progressive nature of this first wave is clearly observed from the time lags as the wave passes through the array starting at PT 1. The second wave, which is the first trailing wave, although much smaller in amplitude also demonstrate progressive behavior in the same direction. However, from the second trailing wave (wave 3) onwards, the characteristics become much more complicated as there are even indications of progressive motion in the opposite direction.

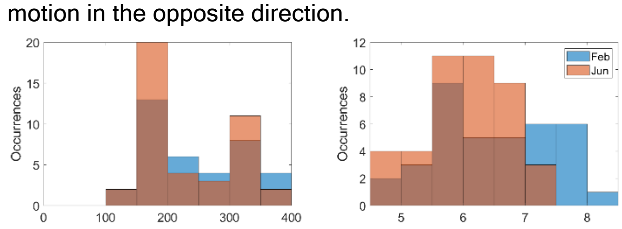

Figure 3 - Histograms of the vessel length (left) and vessel speed (right) from the February and June data sets.

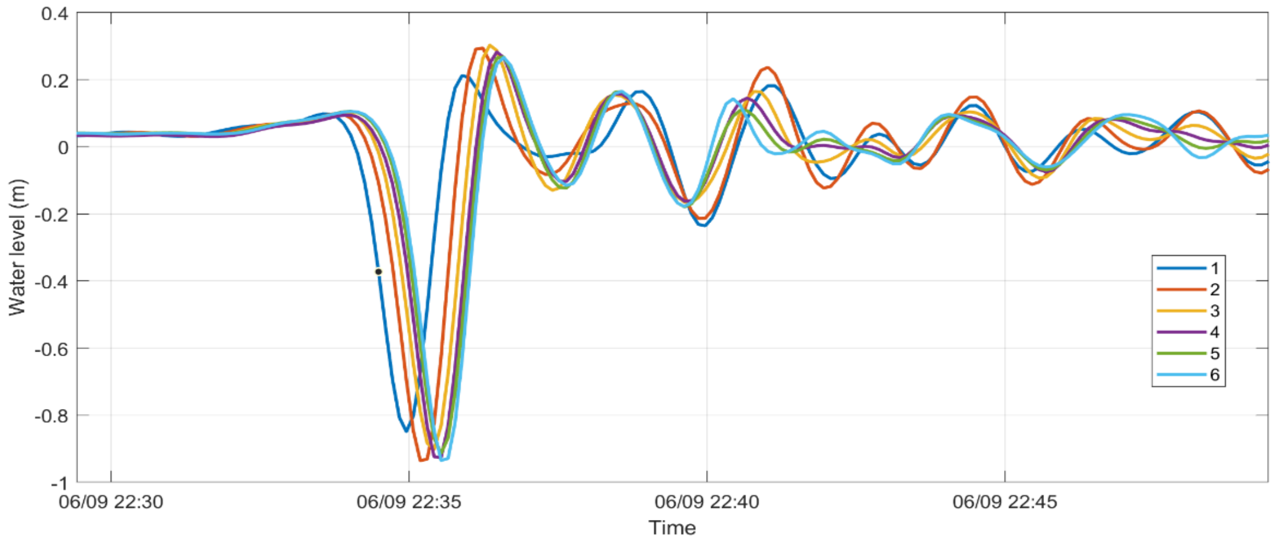

Figure 4 – Time series of the mid-band-pass filtered water level data from each instrument within the longshore array of the Cosco Excellence (366 m long) traveling outbound on June 9, 2022 passing the array around 22:35 moving with an absolute speed about 6 m/s.

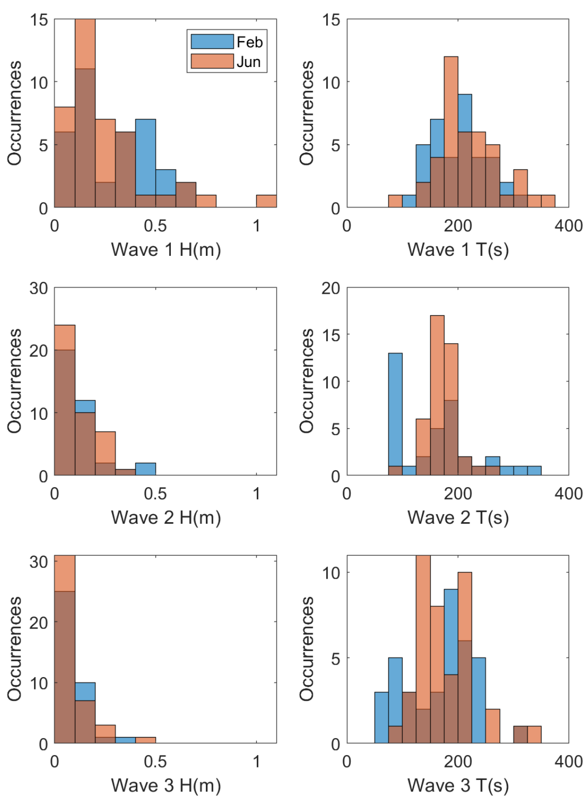

Figure 5 – Histograms of the observed wave height (left column) and period (right column) for the primary "wave 1" (1st row) and the first two trailing waves, "wave 2" and "wave 3" (2nd and 3rd rows, respectively) from the February and June data sets.

The wave heights and periods for the first three waves are computed for each vessel passage and are used to compute the histograms shown in Figure 5. Despite having slower vessels, the June dataset included the largest observed primary wave heights, perhaps from wave shoaling due to that array being in shallower water. The trailing wave heights become decreasingly smaller for both data sets. The periods cover a broad range of values from 100 to nearly 400 s. The primary wave tends to have a longer period than the trailing waves. Interestingly, the first trailing wave tends to have a narrower range of periods than the third wave.

These data sets are going to be further used to analyze the specific characteristics of the trailing waves, in order to determine the presence of progressive and/or standing waves and attribute their generation to the properties of the vessels that created them.

MODELING TRAILING WAVES WITH FUNWAVE-TVD

Cargo ship passages have been simulated with a simplified channel bathymetry in FUNWAVE-TVD, a 2D Boussinesq model. The model simulates the vessel as a pressure source with the same dimensions and speed as a typical cargo ship observed in the field. These initial runs generated trailing waves, which spectral analysis confirmed to be edge waves trapped on the shelf of the channel. Additional suites of simulations were also run with independently varying beach slopes and ship speeds to isolate the effects of these parameters on trailing wave characteristics and confirmed the adherence of the trailing waves to edge wave dispersion.

However, to understand the effect of the more complicated bathymetry and to see if edge waves are still generated, additional simulations will be completed using representative channel cross-sections as measured from the bathymetric survey. These simulations will still utilize a long straight channel, but with a more realistic crosssection. Finally, simulations of vessel passages using the true bathymetry accounting for the along-channel variability will be completed to fully resolve the impact this has on the trailing wave generation and characteristics.

REFERENCES

Garel, Lopez, and Collins (2008): Sediment resuspension events induced by the wake wash of deep-draft vessels, Geo-Marine Letters, vol. 28, issue 4, pp. 215-211.

Haas and Muscalus (2019): Bird-Long Island Management Study Phase 1B: Hydrodynamic Characterizations for Bird/Long Island. No, FHWA-GA-19-1634. Georgia Department of Transportation.