The Effects of Ship-Induced Bernoulli Wakes on the Savannah River, Georgia

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1. Background

The National Ocean Service's Fort Pulaski, GA tidal gauge is the representative tidal observation site for southeast Georgia and portions of the southern South Carolina coast. The gauge is located on the Savannah River, installed on the dock for the Savannah Harbor Pilots (Fig.1). The gauge position is 240 feet from shore and at a depth of 17 feet at mean lower low water (MLLW). Ships traveling between the Port of Savannah and the Atlantic Ocean pass within 580 feet of the tide gauge, the river channel is only 2,015 feet wide. The passing of each moderate to large ship within the narrow channel results in both oscillating waves and a deep depression bore known as a Bernoulli wake (J. Rapaglia et al., 2011). These ship-induced Bernoulli wakes frequently influence the 1-minute and 6-minute tide levels at Fort Pulaski, GA. During high astronomical tide events, the effect of the deep depression bores can result in water levels to exceed Coastal Flood Advisory/Warning criteria or augment water levels already in excess of the flood stage.

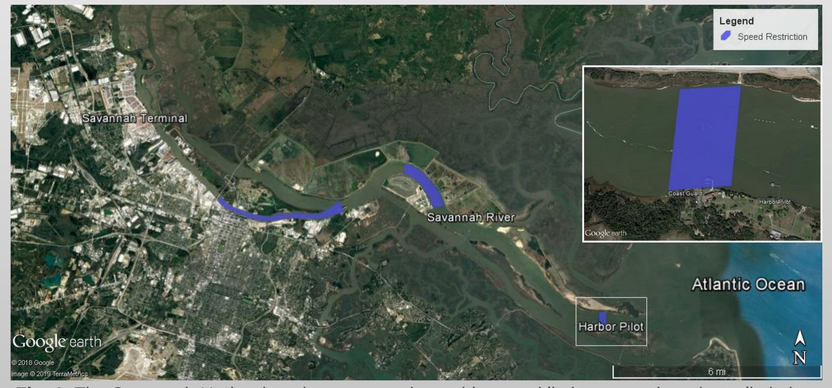


Fig. 1. The Savannah Harbor has three areas where ship speed limits are set in order to limit the size of ship wakes and to protect moored ships and structures from water drawdown. Ship speeds are restricted at the Coast Guard Station, the liquid natural gas facility, and between Old Fort Jackson and the Savannah Terminal (USACE, 2011). Inset area represented by the white box.

2. Analysis Historic Coastal Flood Events

This study looked back at 234 historic flooding events (1997-2018). These events either met or exceeded the Fort Pulaski flood stage of 9.2 feet mean MLLW, using 6-minute data (ex. Fig. 2). Ship wakes were identified by the characteristic trough (V-shaped depression wave) in the 6-minute water level data. Out of the 234 events, 88 events, **38% of flooding events, were augmented by the passage of ships**. Water levels increased from 0.01 to 0.38 feet, with an average increase of 0.06 feet. There were 20 flooding events, or 8.5%, that were the direct result of ship-induced Bernoulli wakes.

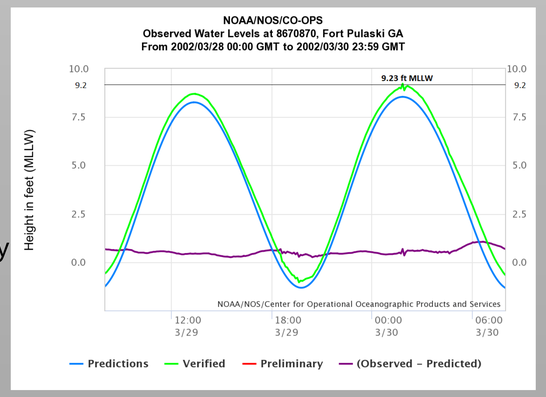
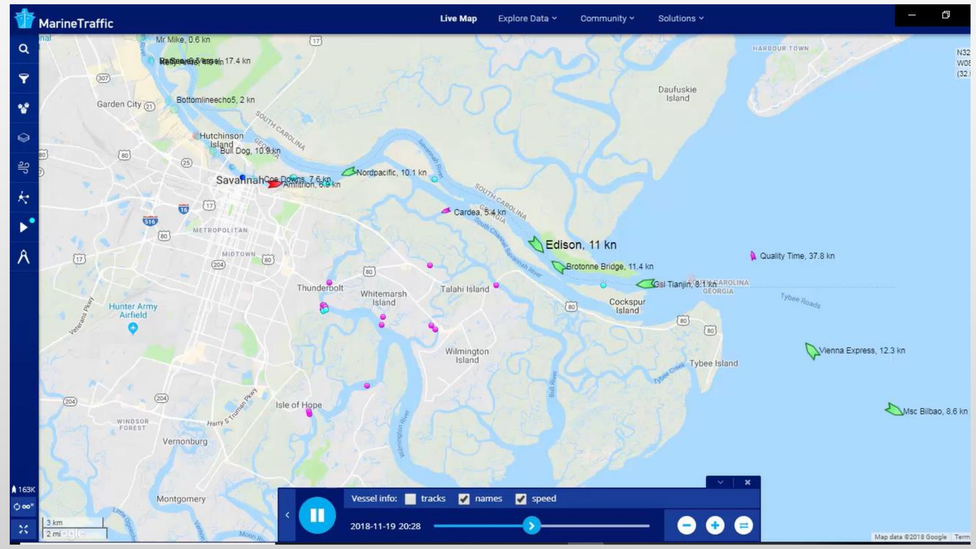
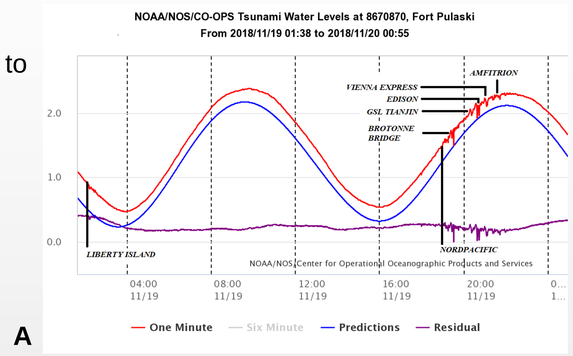


Fig. 2. Example of an ship-induced wake resulting in the observed water level to exceed 9.2 ft. MLLW on 3/30/2002.

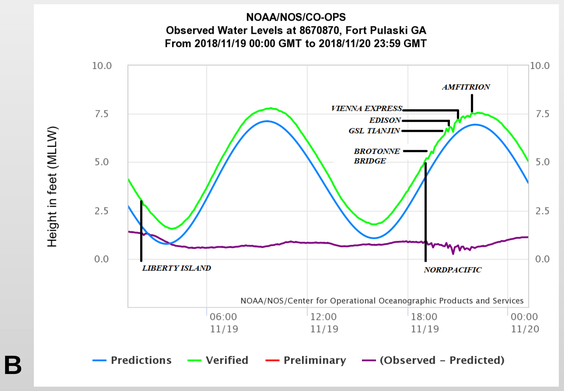
3. Methodology

- This study recorded the 1-minute and 6-minute water level data from the Fort Pulaski tide gauge during the passage of 113 ships (ex. Fig. 3A, B), ranging from standard sized ships to the recently arriving neo-Panamax vessels. The period of study was 10/29/2018 to 3/21/2019.
- The vessel's position, displacement, length, width, draught, and speed were collected in near real-time from the *MarineTraffic* Web site (ex. Fig. 3C).





A



C **B**

Fig. 3. A. Example of 1-minute data and associated ships from 11/19/2018. B. Example of 6-minute data and associated ships from 11/19/2018 C. *MarineTraffic* display of vessels from 11/19/2018.

- The 1-minute and 6-minute data was categorized by the difference between 1-minute high and low values, the difference between the 6-minute high and low values, and the difference in 1-minute values from the ship passage.
- Pearson product-moment correlation coefficient was created to study the relationship between the measured water levels to the ship's water displacement (tonnage), length, width, draught, speed, Froude, length Froude, and blocking coefficient.

Table 1. Average difference between 1-minute high and low values, 6-minute high and low values, and difference in 1-minute data with ship passage. Averages listed by vessel types and for all 113 ships.

Vessel Type (Length x Width x Draught)	1-Min Diff (ft.)	6-Min Diff (ft.)	1-Min High vs. Initial (ft.)
Early Container (137m x 17m x 9m)	0.30	0.16	0.02
Fully Cellular (215m x 20m x 10m)	0.33	0.09	0.10
Panamax (250-275m x 32m x 12.5m)	0.48	0.15	0.14
Post Panamax (280-335m x 40m x 13m)	0.72	0.24	0.20
Neopanamax (366m x 49m x 15.2m)	0.83	0.24	0.21
Average	**0.53**	**0.18**	**0.13**

4. Results

- The passage of 113 ships showed a relationship between the ship size and observed 1-minute and 6-minute water levels. Generally, **the larger ships resulted in greater changes in water levels (Table 1).**
- Pearson product-moment correlation coefficient (CC) indicated that the ship length and width had the greatest correlation with difference between 1-minute (0.48 CC) and 6-minute (0.25 CC) water levels (Fig. 4).
- The 6-minute data was less impacted by the ship-induced Bernoulli wakes than the 1-minute data. The typical duration of ship wakes is ~400 s, solitary trough lasting ~80 s (K.E. Parnell et al., 2015).

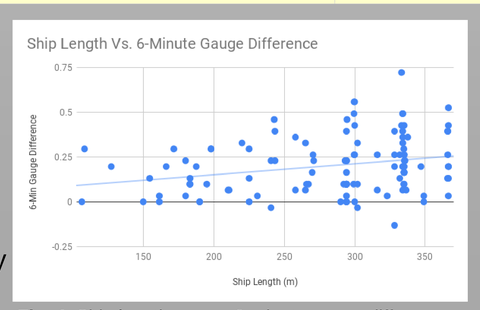


Fig. 4. Ship length versus 6-minute gauge difference

References and Disclaimer

K.E. Parnell et al., Ship-induced solitary Riemann waves of depression in Venice Lagoon, Phys. Lett. A (2015), https://doi.org/10.1016/j.physleta.2014.12.014

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U.S. Army Corps of Engineers (USACE). 2011 Reanalysis of Ship Forces at the Shoreline using Updated Draft Information, Savannah Harbor, Savannah, Georgia July 2011

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