NEP Fowl River Marsh Study 2018 Final Report

Project Abstract

This component focused on salinity dynamics due to the potential ecosystem implications associated with changing salinity exposure on marsh platform vegetation. To understand how Fowl River and the associated land spits are changing temporally and spatially, time series data were collected during the selected study period (May 1- July 11, 2018) from five monitoring stations within the system to support the ecological and biogeochemical sampling. System salinity generally increased over the course of the study period, consistent with reduced discharge expected during the transition from spring to summer, and there was significant temporal variability in the salinity signal with low frequency changes on the order of 4-8 practical salinity units (psu) over day-to-week time scales. The salinity dynamics in Fowl River are clearly influenced by the conditions from both Mississippi Sound and Mobile Bay, as an interior site was, at times, saltier than the mouth of Fowl River. During periods of low discharge, wind conditions, through changes in water level, represent an important forcing mechanism controlling salinity variability. Finally, the close relationship between wind conditions and water level have indirection implications for the impacts of salinity under rising sea level. These results suggestion that as sea level rises, the impacts of salinity will more strongly affect the system.

Motivation

The success of estuarine restoration efforts often depend on a range of interdisciplinary marine and fluvial processes that interact in complex ways. Physical forcing is a critical factor in controlling the environmental conditions in which biogeochemical and ecosystem processes must operate. Thus, a major consideration in estuarine restoration are the physical conditions at site locations due to their importance in determining whether biological organisms can survive and flourish. As highlighted by Bates et al. (2018), it is essential for biologists to understand how systems are changing both locally (as compared to globally) and temporally (at 'ocean weather' time scales). To that effect, high frequency measurements (~ hourly) are critical to better understanding relationships between environmental forcing, hydrographic changes, and subsequent biological response over a broad range over spatial and temporal scales.

While many environmental conditions in an estuarine system can change quickly, this study focused on salinity dynamics due to the potential ecosystem implications associated with changing salinity exposure on marsh platform vegetation. The extent to which salt enters an estuarine system depends on several parameters, with classic estuarine studies focused on the impacts of freshwater discharge (Abood 1974; Garvine et al. 1995; Monosmith et al. 2002). However, a number of studies highlight the importance of wind forcing in modifying the salinity dynamics, where both wind direction and magnitude can both change the extent over which salinity impacts in a system (Scully et al. 2005; Ralston et al 2008; Coogan and Dzwonkowski 2018). This study focused on characterizing the high frequency temporal and spatial variability in the horizontal salinity structure of the system during the spring/summer season, when marsh growth rates are typically high. In addition, the main drivers controlling the extent and duration of salt intrusions into the system are investigated to provide key information on the factors that would be expected to lead to periods of enhanced salt inundation and potential salinity stress on the marsh platforms. By providing a characterization of the system salinity field as well as the associated drivers, a better understanding of their impact on ecosystem processes and the likelihood of restoration success can be achieved. This new information on salinity dynamics will be critical to informing management of the existing habitats as well as identifying ideal restoration sites.

Data and Methods

Time series data were collected during the selected study period (May 1- July 11, 2018) from various monitoring stations in order to support the ecological and biogeochemical sampling. Within the estuary, the data were primarily derived from YSI 6600 V2 and V4 water quality sondes located at four sites in Fowl River (Fig. 1), including a site at the mouth (0 km), at Bellingrath Gardens (4.3km), at an upriver spit (7.3 km) and at the Fowl River bridge (11.3 km). In addition, an Arduino-based sonde developed by Dauphin Island Sea Lab (Lockridge et al. 2016) was deployed at the mouth of West Fowl River. The YSI 6600 instruments measured temperature, salinity, dissolved oxygen, and pressure at depths of ~0.25 m off the bottom (site water depths ~3-5 m) and the Arduino-based sonde measured only temperature and salinity. The sampling frequency was Δt = 5 minutes for the YSI 6600s and the Arduino. The YSI 6600 sondes were cleaned and calibrated every 3-4 weeks during the 10-week study period. The Arduino-based sonde was changed out approximately half way through the study period. These data were compared to available CTD casts at the deployment and recovery times as well as despiked to ensure high quality measurements. The four Fowl River sites were distributed along an expected salinity gradient to characterize changes over the extent of the system (Fig. 1). The West Fowl River site was intended to assess any influences from the Mississippi Sound. Velocity data from 2 acoustic Doppler current profilers (ADCPs), an acoustic Doppler velocimeter (ADV), and 4 tilt meters were collected at the 4 Fowl River sites, but are beyond the scope of this work. Details regarding water velocity data collection can be found in the Coogan and Dzwonkowski (Submitted 2019).

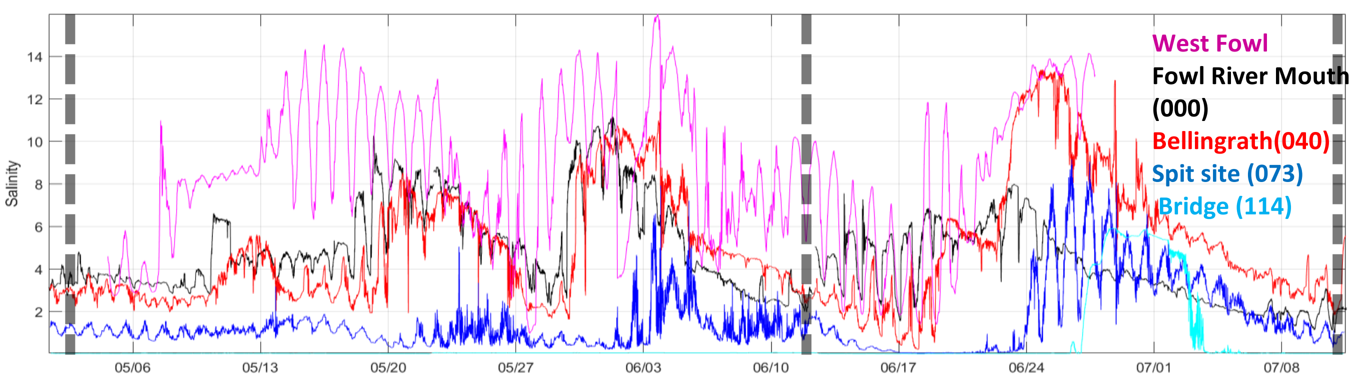
Additional environmental data, including meteorological data, freshwater discharge, and water levels, were obtained from various sources (Fig. 1). Hourly wind data were collected from

Fig 1. Locations of time series stations in Fowl River and West Fowl River during the May-July study period. The ● were short-term deployment stations measuring near-bottom water properties (temperature, salinity, and dissolved oxygen and velocity (at station 00, 04, 07 and 11). The △ are long-term water level stations support by NOAA NOS.

the NOAA National Data Buoy Center (NDBC) station DPIA1 at Dauphin Island. Daily discharge data for Fowl River were obtained from a U.S. Geological Survey gaging station (30°30'02" N, 88°10'53" W: USGS 02471078). The study period data (May-July 2018) is listed as “provisional” on account of USGS waiting to review the data until the end of each water year (i.e., October). Hourly water level data were obtained from a regional NOAA tide stations at Dauphin Island, Alabama (station ID: 8735180) as well as two sites including one at the mouth of Fowl River (station ID: 8735523; near our mouth site) and one at the mouth of West Fowl River (station ID: 8738043; near our West Fowl River site). These water level data were demeaned so that differences in the site responses could been readily compared. Data from DI were considered to be representative of water level along the coast (hereinafter referred to as coastal water level).

Several basic procedures were applied to the time series data. With a few exceptions, the data were generally continuous, any gaps associated with the despiking process were filled using linear interpolation. All data collected at frequencies higher than hourly were averaged to hourly to match the additional environmental data. Wind data at Dauphin Island, measured at 13.5 m above sea level, were standardized to10 m above sea level using a log wind profile. Given the coastline orientation, the east-west component of the wind vector was used as the along-shelf component consistent with previous work in the region (e.g. Dzwonkowski and Park 2012). In addition, Fowl River is connected to both Mobile Bay and Mississippi Sound with perpendicular primary orientations of north/south and east/west, respectively. With the exception of daily freshwater discharge, a low pass 40-hr Lanczos filter was used to isolate low frequency processes in the time series data.

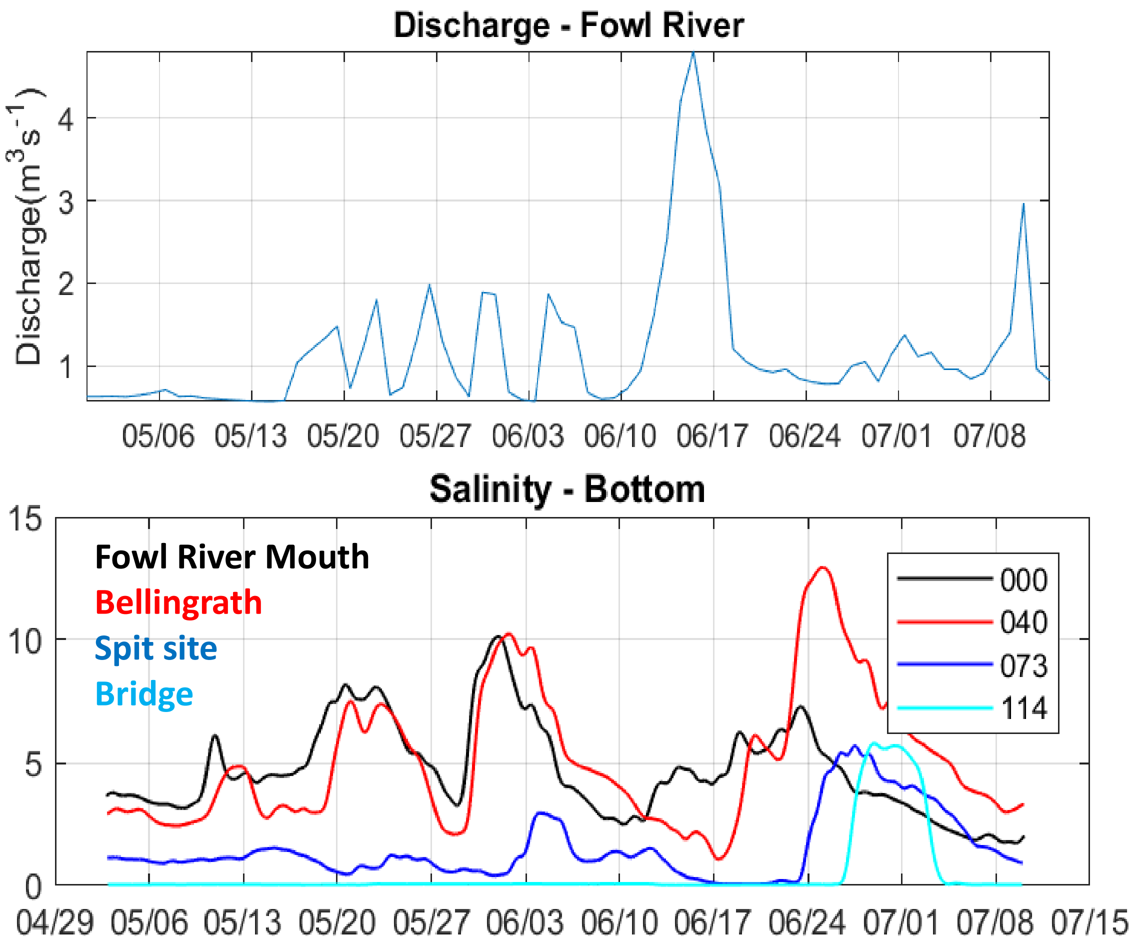
Figure 2 Times series of instantaneous salinity data from the short-term deployment stations during 2018.



Salinity Patterns

Time series of the salinity data from the five stations showed both spatial and temporal variability (Fig. 2). Spatially, the sites ranged from brackish to completely fresh. The West Fowl River site was consistently the saltiest site and had the largest tidal signal. In contrast, the bridge site had no tidal signal and was completely fresh the majority of the study period. Over the 10 week study period there were three prominent intrusions of salt that propagated into Fowl River to varying extents (~May 20, Jun 01, and Jun 26). From the stations in Fowl River, the progression of salt into the estuary during the events exhibited a general pattern of an increase in salinity being initiated at the Fowl River Mouth site and subsequently increases at stations further into the river. Over the course of the study period the extent of these salinity intrusions increased over time with the first event (May 20) being observed at only the Fowl River Mouth and Bellingrath sites (approximately ~4.3 km into the estuary), while the third intrusion event extended beyond all the sites with salinity values of nearly 6 psu at the bridge site, ~11.4 kms into the estuary.

Figure 3 Times series of the river discharge at the USGS Fowl River gage (Top) and the low-pass salinity signal along the Fowl River stations (Bottom)

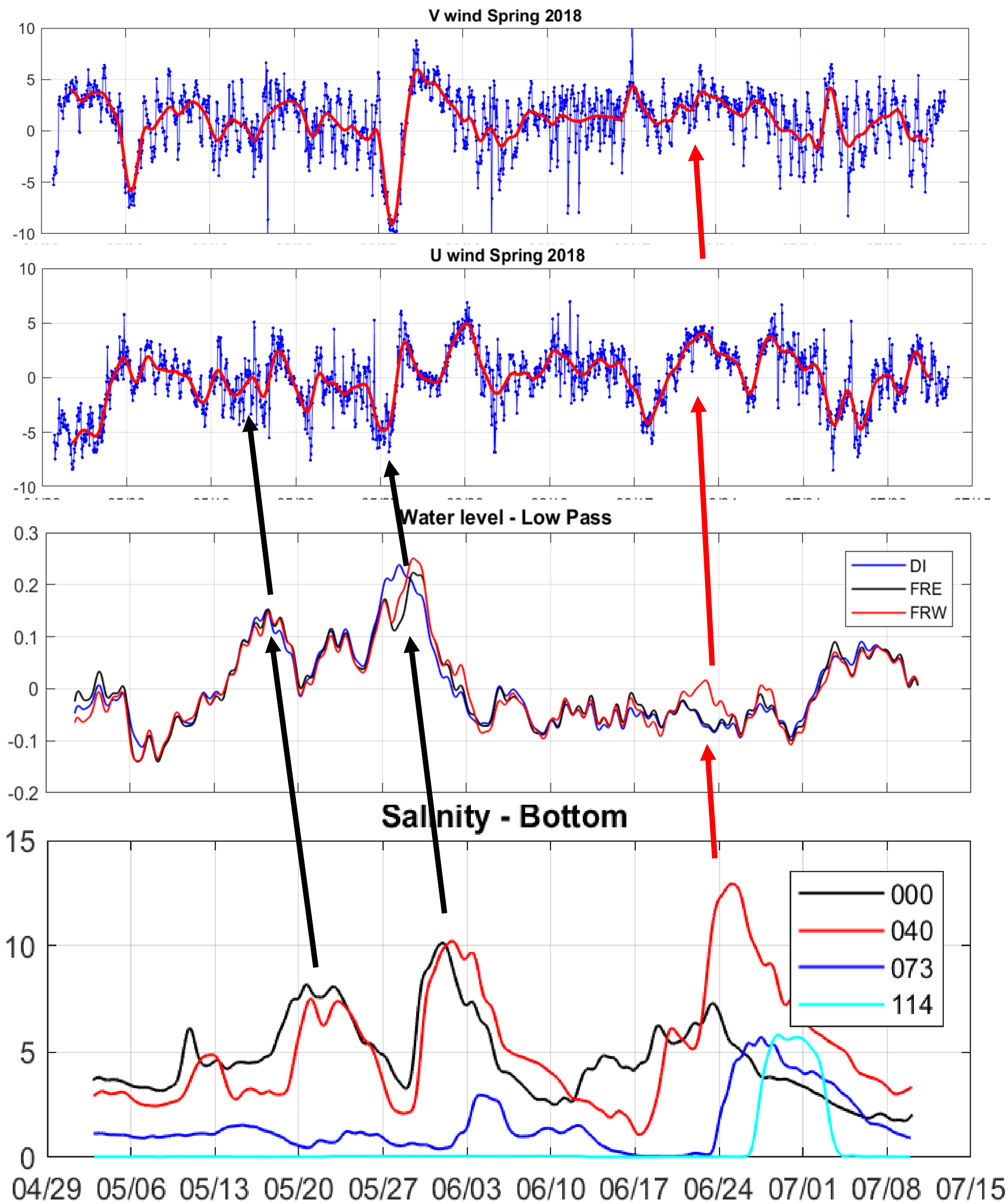


Each event had some subtle differences and the influence from the Mississippi Sound was consistently observed at the Bellingrath site as it was saltier than the Fowl River Mouth Site to varying extents during each event. This salinity signal at the Bellingrath site was particularly notable in the second and third intrusion events. The second event began with a pulse of high salinity at the mouth of Fowl River that subsequently increased at the Bellingrath site. Following the salinity peak at both of these sites, there was an extended period (~9 days, June 2 to June 11) when the salinity remained 2 psu higher at the Bellingrath site. The third event has a somewhat different salinity pattern with a larger delay in the salinity increase between the two sites as well as a much larger peak in salinity, ~6-8 psu higher at the Bellingrath site compared to the Fowl River Mouth site. Tellingly, the salinity increase followed a large salinity increase at the West Fowl River site and the salinity values and patterns nearly overlapping at these sites (Fig. 2).

Given the predominance of these three multi-day to week events, the low frequency signal in the salinity are compared to environmental conditions to better understand the forcing response of the system (Fig. 3 and 4). River discharge feeding the system was relatively low during the study period with flow at ~1 $m^3 s^{-1}$ for most of the study period (Fig. 3a). There was one multi-day event (6/11-6/18) with elevated discharge peaking around 4 $m^3 s^{-1}$. The salinity response to this signal was not clear. The Fowl River Mouth site actually increased in salinity during this event. While the interior sites did decrease to some extent in conjunction with the discharge event, the largest changes in salinity were not coupled with the river discharge. While the mean salinity conditions of the system were likely set by the interaction of river discharge with the two outlets (Fowl River and West Fowl River), the low frequency salinity variability was primarily driven by other mechanisms.

Time series of other environmental conditions provided additional insight on the system salinity dynamics. Water level from three regional sites had a generally consistent response across the region. There was some notable variation between sites around May 28 and again on Jun 23. Comparing the water level data against the salinity time series indicated that early in the time series the increases in water level were associated with increases in salinity (e.g., May 18) while later in the study period the time series captured increases in salinity associated with differences between West Fowl River and Fowl River water levels (e.g., Jun 23). As a result, the characteristics of the salinity response were notably different. The May 18 water level event, where the water uniformly increased at all three sites (in the main stem of Fowl River), resulted in a sequential increase in salt that propagated upriver reaching three of the Fowl River sites. In contrast, the water level difference during the Jun 23 event, with West Fowl River being higher, lead to an intrusion event centered at the Bellingrath site. This is the location where Fowl River bifurcates, forming the direction connection to West Fowl River. The second event (Jun 28) appeared to be a blending of the two types of events where the water level initially rose uniformly and then deviated, which resulted in a sequential increase in salinity that then transitioned to an event with the highest salinity at the interior Bellingrath site. It is worth noting that this event was associated with the passage of Tropical Storm Alberto so the salinity response to water level condition likely had complicating factors.

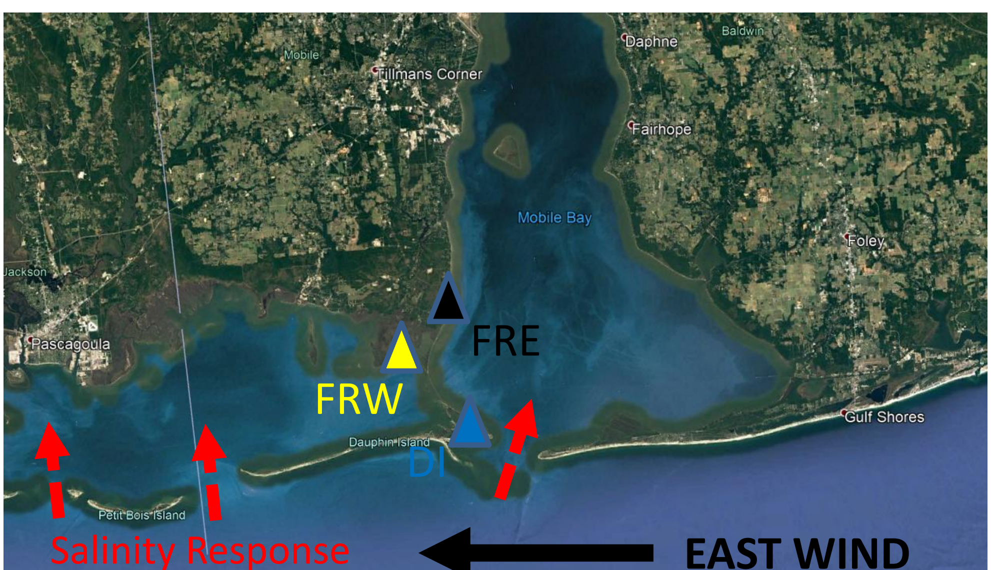
Figure 4 Time series of north/south (V, +/-) wind (first panel) and east/west wind (U, +/-) from Dauphin Island (second panel), demeaned low pass water level from regional stations (third panel), and low pass salinity signal from the Fowl River stations (fourth panel). The red and black arrow highlights two different types of salinity intrusion impacting the Fowl River and the associated spits. The black arrow are remotely forced events (Fig 5.) and the red arrow are locally forced events (Fig. 6).



Connection to Wind Forcing

The relationship between salinity and water level naturally leads to mechanistic questions about water level variability. Wind forcing is a well-established mechanism for modifying coastal water level and representative wind conditions for the region are shown in Figure 4a and c. During the first event, the wind conditions are predominately out of the east. The along-shore direction, relative to the Alabama/Mississippi coastline, is consistent with coastal Ekman dynamics generating a downwelling event driving sea level set-up at the coast. While the winds were relatively light, the persistent conditions, ~6 days, likely generated a cumulative effect on the water level. This is considered a ‘remote’ forcing as interior water level changes in response to a change at the system boundaries (Fig. 4). There was some hint of the remote effect during the third event, around June 17, where there was a slight sequential increase at both the Fowl River Mouth and Bellingrath sites. However, this event was dominated by the surge in salinity at the Bellingrath site (and the upstream salinity propagation), which occurred under a period of southwesterly winds. These wind conditions were ideal for generating a local forcing in Mississippi Sound/Portersville Bay, where direct wind forcing sets up water level slope at the downwind end of the system. This effect would be expected to result in higher water level at West Fowl River relative to Fowl River Mouth, and thus generating a barotropic pressure gradient that would be expected to force water from Mississippi Sound into Fowl River (Fig. 6). This was consistent with the salinity response to such events in the study period. It is worth noting that the local wind forcing within Fowl River was small as the system is narrow and sinuous so that no predominate wind direction is likely to have enough fetch to generate an appreciable circulation throughout the interior of the system. Thus, the local effect of the wind forcing in Mississippi Sound/Porterville Bay is still a remote effect in that it is derived from an external forcing on the boundary of the system.

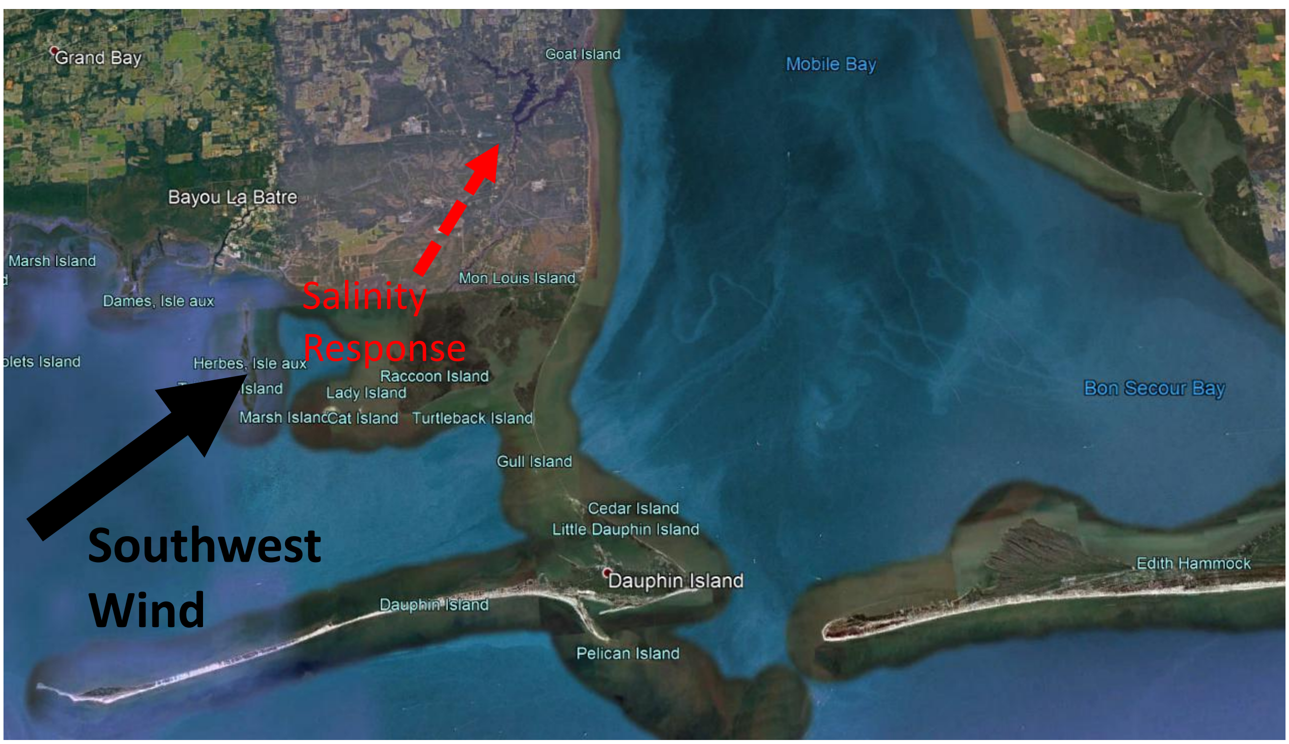
Figure 5 Conceptual diagram of the coastal wind forcing (large black arrow) in reference to the water level station at Dauphin Island (DI) and along Fowl River (FRE)/West Fowl River (FRW) and the associate salinity intrusion (red dashed arrows). The along-shelf wind sets up coastal water level (via Ekman transport) which subsequently forces Gulf of Mexico water into adjacent estuaries and bayous as implied from the time series data



Finally, the strongest wind conditions during the study period were associated with the second event when Tropical Storm Alberto influenced the region. The wind conditions were initially out of the east-northeast and then they rotated to south-southwest. Thus, the initial easterly winds led to a 'remote' effect associated with coastal setup, followed by a 'local' water level gradient generated by the southwesterly winds. As a result, the salinity response was mixed with an initial sequential salinity increase in the system that was followed by a persistent elevation in salinity at the Bellingrath site (relative to the Fowl River Mouth site).

The salinity response to wind forcing (via changes to water level) is somewhat limiting in that only three large intrusion events were observed in the time series. This small sample size represents statistical challenges as the salinity response to forcing conditions can be difficult to quantify due to the potential non-linear behavior of salinity time series that arises from several competing controlling factors (e.g. river discharge, oceanic changes, tidal straining, wind mixing, etc.). For example, the tail end of the time series had a remote wind event (July 1-8) that increased the water level, but did not have a clear salinity response. The reason for the lack of salinity response is unclear. However, this data does indicate that monthly or seasonal sampling that is common in ecological studies could lead to significant aliasing of the salinity conditions, at least during the transition from spring to summer seasons when discharge is low.

Figure 6 Conceptual diagram of the implied salinity intrusion (red dashed arrow) into Fowl river during Southwest wind events (black arrow) captured during the times series measurements. The thick black arrow represents the wind stress and the red dashed arrow indicates how higher salinity water from the Mississippi Sound is forced through West Fowl River into Fowl River during these wind events.



In addition, the characteristics of the salinity signals were generally consistent with expected responses to wind-driven physical forcing where two types of remote wind events were influencing the system. Interestingly, the intrusions associated with the ‘local’ type of remote wind forcing appear to be more effective at bringing salinity into the spit region. Although this ‘local’ type of remote wind forcing occurred later into the summer season when the estuarine conditions would be expected to have an increased marine influence so the impact maybe be amplified as a result of the seasonal timing of the event. To get a better sense of the relative importance of remote verse local wind forcing on this system, long-term time series of wind and water level can be explored to assess the frequency and consistence of coastal setup and local setup. Future work could using long-term station data to show correlations between East wind and coastal water level and Southeast wind and the set-up between West Fowl River and East Fowl River following conventions of Wong et. al. (2009). Addition work could also look at DI station salinity with water level to potential determine whether increases in water level are associated increase is salinity over multiple years.

Summary

System salinity generally increased over the course of the study period, consistent with reduced discharge expected during the transition from spring to summer.

There was significant temporal variability in the salinity signal with low frequency changes on the order of 4-8 psu over day to week time scales.

The salinity dynamics in Fowl River are clearly influenced by the conditions from both the Mississippi Sound and Mobile Bay as an interior site was, at times, saltier than the mouth of Fowl River.

During periods of low discharge, wind conditions, through changes in water level, represent an important forcing mechanism controlling salinity variability

Two types of wind forced intrusions were observed: remote forcing events of coastal origin and remote forcing events of local origin. Remote forcing events of coastal origin altered water level at the coastal line and subsequently pump salt into estuary, whereas remote wind forcing of local origin resulted from local wind forcing changing the water slope in the main estuaries adjacent to the sub-estuary and ‘pushing’ salt into the system (via a barotropic pressure gradient).

Finally, the close relationship between wind conditions and water level have indirection implications for the impacts salinity under rising sea level. These results suggestion that as sea level rises, the impacts of salinity will more strongly affect the system.

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