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Tidal and residual circulation in the St. Andrew Bay system, Florida

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ABSTRACT

Two 24-h surveys were conducted in St. Andrew Bay, Florida, during spring and neap tides to describe the tidal and non-tidal circulation patterns and to determine the factors that affect these patterns. In particular, the effect of tidal forcing in modulating such circulation patterns was explored. Observed velocities were fitted to diurnal and semidiurnal harmonics separating tidal motions from sub-tidal motions. Residual flows were compared with an analytic model that allowed variations in the relative contributions from Coriolis acceleration and friction using the Ekman number. A solution with an Ekman number of 0.04 resembled the observations best and indicated that the hydrodynamics were governed by pressure gradient, Coriolis and friction. Locally, advective accelerations became important around headlands in sub-estuaries in the system. The consistency of the mean pattern from October to March suggests that tides play a minor role in modulating the exchange flow. Deviations from the long-term mean are mainly caused by wind-driven coastal setup and setdown.

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1. Introduction

The northeastern Gulf of Mexico coast is experiencing rapid urban and suburban development that intensifies pressure on regional estuaries. Determining the effects of coastal development on various biological and chemical processes in these estuaries (Lindall and Saloman, 1977) depends on understanding the underlying physical framework, namely estuarine circulation.

Most studies of estuarine circulation have taken place at temperate latitudes where tidal strength is an important agent in modulating the net circulation. For instance, asymmetries in the flood and ebb tide due to bottom friction and non-uniform bathymetry can induce residual flow (Stommel and Farmer, 1952; Fisher et al., 1979; Robinson, 1981; Geyer and Signell, 1990). Modulation of tides by the spring/neap cycle generates a fortnightly frequency on tidal pumping of salinity up an estuary (Jay and Smith, 1990; Hibiya and LeBlond, 1993). Net exchange flows tend to be strongest at neap tides, when tidally induced mixing is the weakest (Nunes and Lennon, 1987).

Tides in subtropical systems along the Gulf of Mexico exhibit small ranges (<0.5 m) compared to temperate estuaries (>1 m). Effects other than tidal modulation and asymmetries could play a larger role in altering the residual circulation. Many subtropical systems show seasonal fluctuations in river runoff that impose an annual cycle to their stratification (Schroeder et al., 1990) and hence its circulation (Valle-Levinson et al., 2001). Other studies of subtropical systems along the Gulf of Mexico have found 3–5 day coherence between increased sub-tidal exchange and meteorological forcing associated with passing fronts (Smith, 1977; Swenson and Chuang, 1983). Transient fronts have a two-fold effect. First, water exchange between a lagoon and the adjacent ocean may be influenced by the inverse barometer effect (Liu, 1992). In addition, direct sea level set up by the Ekman transport (Wong, 1987) or advection by onshore winds (Smith, 1979) may drive water into and out of these lagoons at volumes larger than the tidal prism.

Pritchard's (1955) two-layer model, resulting from river input at the head of an estuary, is not applicable to many subtropical lagoons. Systems with low freshwater forcing, ubiquitous along the Gulf of Mexico, have weak baroclinic flows easily modified by external forces. The amount of freshwater, the meteorological forcing and the strength of the tidal currents are crucial in determining whether the system is driven by density gradients, tides, or winds. The objective of this study is to determine the spatial structure of the circulation in a subtropical estuary with quasi-steady freshwater input. In particular, this investigation seeks to assess the role of tidal forcing in modifying such a spatial structure. This objective is addressed with data collected at St. Andrew Bay, Florida, during spring and neap tides at different times of the year and by comparing the results to a theoretical model.

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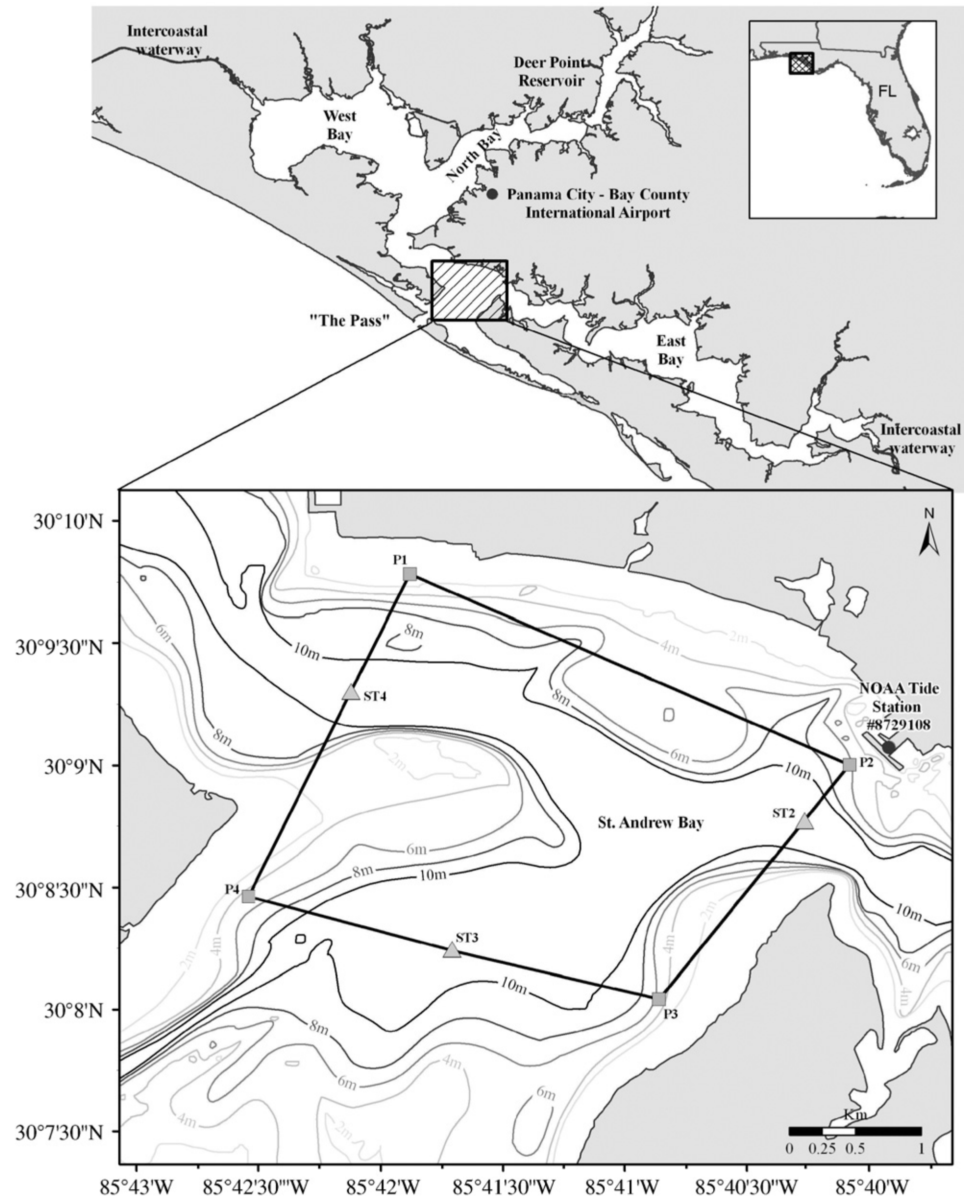

Fig. 1. Map of the St. Andrew Bay system and study area. Transect 1 = P1–P2. Transect 2 = P2–P3. Transect 3 = P3–P4. Transect 4 = P4–P1. ST 2, ST 3, ST 4 = CTD Station.

2. Study area

The St. Andrew Bay system in northwest Florida (Fig. 1) is an ecologically important estuary surrounded by rapidly growing communities. The bay is home to one of the most diverse marine populations of any estuary in the northern Gulf of Mexico coast (Ogren and Brusher, 1977). This area hosts a large variety of fauna because of, among other reasons, its low freshwater inflow, low turbidity, extensive sand flats, widespread submerged aquatic vegetation (SAV), and a deep basin with both coarse and fine sediments (Brusher and Ogren, 1976).

The St. Andrew Bay system is a drowned river valley, coastal plain estuary that formed 5000 years ago during the Holocene transgression (Salsman et al., 1966). The system consists of four sub-estuaries: North Bay, West Bay, East Bay, and St. Andrew Bay (Fig. 1). The latter is the only sub-estuary with a direct connection to the Gulf of Mexico. The US Army Corps of Engineers maintains a 150 m wide channel at the Gulf of Mexico connection, known locally as "The Pass," which is armored with jetties on either side. A minimum 9 m channel depth is maintained from the Pass to the Port of Panama City (St. Andrew Bay) and a paper mill (East Bay), although the channel depth usually exceeds 15 m. Channels in all of the sub-estuaries are generally parallel to the shoreline and are maintained at 4 m. West Bay and East Bay connect to the Gulf Intracoastal Waterway, which allows sheltered navigation from Choctawhatchee Bay to Lake Wimico. The surface area of the bay system is 243 km^2. The watershed is approximately 2800 km^2 (USEPA, 1999) and is located entirely within Florida (NWFWMD, 2001).

Besides non-point runoff and assorted small creeks, the largest freshwater source draining into the estuary is the spillover from the Deer Point Reservoir (Fig. 1). This human-made lake is located at the head of North Bay and is formed as a result of a dam constructed downriver from the confluence of several spring-fed creeks, primarily Ecofina Creek. Daily flow rates are calculated by the Bay County Water Division.

Tides in the system are typically diurnal with a mean range of 0.5 m, with a longer ebb flow than flood flow (Ichiye and Jones,