THIN-LAYER GRAVITY CURRENTS IN A SHALLOW ESTUARY

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Abstract
A 48-hour field study conducted at the nexus between Oso Bay and Corpus Christi Bay (Texas) shows the development of cyclic thin-layer gravity currents initiated during an ebbing tide by hypersaline water in Oso Bay. Although the gravity current is in shallow water (depth < 4 m) and daily wind speeds peak at 20 kph, the thin-layer stratification induced by the gravity current persists over multiple tidal cycles. Two kilometers from the origin of the gravity current, a region of hypoxic (low dissolved oxygen) water is observed over the duration of the study.

Field study
We might expect that an estuary of 3-4 m depth with daily wind speeds peaking at 20 kph should be vertically well-mixed and exhibit only horizontal salinity gradients. However, Corpus Christi Bay (Texas) is adjacent to the Laguna Madre estuary and Oso Bay, which are sources for underflowing hypersaline gravity currents. A cyclic, thin-layer gravity current was observed in a field study conducted over a 48 hour period during August 22-24, 2005 at the nexus of Oso Bay and Corpus Christi Bay. The study used a Eureka Manta water quality profiler to measure conductivity, temperature and dissolved oxygen (DO) at ten sampling stations shown in Figure 1. The profiler logged data at ~15 cm intervals with additional data point ~5 cm above the bottom and at the bottom. A boat-mounted RDI Acoustic Doppler Current Profiler (ADCP) was used to measure velocity profiles across the channel between the bays. WinRiver ADCP software was used to estimate the volume flow rate between the bays. Solinst model 3001 Levelogger pressure transducers were used to record the water surface elevation within Oso Bay and in Corpus Christi Bay outside the channel. Wind speed and direction were collected with a CES Zeno 3200 weather station. Environmental conditions during the study period are shown in Figure 2.
Results

The profiles from sites 300 to 308 were collected sequentially to provide transects of data from the channel out into Corpus Christi Bay. Each transect required between 1-2 hours to complete and can be considered quasi-synoptic data. Contours from the transect data are shown in Figures 3-5. It can be seen that when the flow is out of Oso Bay (e.g. negative inflows T2 from Fig 2b), a high salinity layer plunges under Corpus Christi Bay. During the late afternoon and early evening (e.g. T2 and T3) the underflow has both high temperature and high DO. In contrast, early morning high salinity underflows (e.g. T8 and T9) are low temperature and low DO. At station 308 (~ 2 km from the channel) the water near the bottom remains is hypoxic throughout the study period.

Figure 2. Environmental conditions during study. Error bars are mean values ±1 standard deviation. (a) water surface elevations, (b) ADCP-measured flow rate and water surface elevation difference between bays, (c) wind speed and direction binned in 15 minute intervals.
Figure 3. Contours developed from field data; x-axis distance = 0 m is station 300, distance = 2100 m is station 308 in Figure 2.
Figure 4. Contours developed from field data; x-axis distance = 0 m is station 300, distance = 2100 m is station 308 in Figure 2.
Figure 5. Contours developed from field data; x-axis distance = 0 m is station 300, distance = 2100 m is station 308 in Figure 2
Discussion

Stratification and hypoxia are not unknown in Corpus Christi Bay (e.g. Montagna and Kalke, 1992; Ritter and Montagna, 1999; Applebaum et al. 2005); however the physical mechanisms leading to shallow-water stratification in this estuary have not previously been investigated. In this field study and another (presently being analyzed), we have observed salinity gradients of 10+ psu over as little as 20 cm, which inhibits rapid mixing by wind-driven turbulence. Our preliminary analysis indicates there are two principal types of underflows in Corpus Christi Bay leading to strong stratification. The first type of underflow (described above) is a thin-layer flow (~0.4 m) that results from daily flood/ebb tidal exchanges. When the ebb tide allows hypersaline water to enter Corpus Christi Bay, the resulting dense gravity current is still a coherent feature more than 12 hours from initiation and more than 2 km from the shoreline. This thin-layer current leads to low dissolved oxygen (DO) levels (hypoxia) during the night as respiration rapidly depletes dissolved oxygen in the thin layer, and mixing rates are insufficient to maintain an oxygen supply from the surface. Simple scaling analysis indicates the thin-layer underflow should mix before causing hypoxia for wind speeds above 30 kph. The second type of underflow (data not presented) is initiated by high wind events (sustained speeds above 25 kph) out of the south that transport a large volume of hypersaline water out of Laguna Madre and into Corpus Christi Bay. Although such sustained high wind speeds eventually lead to complete vertical mixing, the volume of hypersaline water entering Corpus Christi Bay appears to allow development of a thicker gravity current (~1.5 m) that may persist for four days or more and extends more than 7 km into the bay before being mixed. The extended duration and coverage of the thick-layer gravity current leads to more hypoxia than does the thin-layer current.

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