Houston Galveston Bay GPS

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Project
» RAPID: Capturing the Signature of Hurricane Harvey on Texas Coastal Lagoons (Hurricane Harvey Texas Lagoons)

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Abstract
Quantifying the direction and magnitude of CO2 flux in estuaries is necessary to constrain the global carbon cycle, yet carbonate systems and CO2 flux in subtropical and urbanized estuaries are not yet fully determined. To estimate the CO2 flux for Galveston Bay, a subtropical estuary located in the northwestern Gulf of Mexico proximal to the Houston-Galveston metroplex, monthly cruises were conducted along a transect extending from the Houston ship channel to the mouth of Galveston Bay and Gulf of Mexico from October 2017 to September 2018. Underway pCO2 measurements were recorded using a Shipboard Underway pCO2 Environmental Recorder (SUPER-CO2) system. CO2flux was calculated for 0.025° x 0.025° latitude increments along the transect and total CO2 flux for the Bay was estimated. Mean Bay water pCO2was 384.2 ± 56.7 µatm. A large freshwater inflow event in spring was followed by a period of dilution (low salinity, TA, and DIC) and enhanced primary production (low pCO2, water, CO2 uptake, and high chlorophyll-a levels). CO2 flux exhibited large seasonal and spatial variability, likely primarily due to seasonality in photosynthesis and variability of freshwater inflow events. Overall, Galveston Bay was a sink for CO2, with a mean air-sea CO2 flux of -8.3 ± 17.3 mmol m-2 d-1, and carbonate chemistry in Galveston Bay was regulated by an interaction between hydrology and biogeochemistry. The carbonate chemistry and CO2 uptake patterns of Galveston Bay differ from those that are common in temperate estuaries, which reiterates the need for further research in subtropical estuaries.

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Coverage

Location: Galveston Bay, an estuary situated adjacent to the Northwest Gulf of Mexico
Spatial Extent: **N**:30 **E**:95.5 **S**:29 **W**:94.5
Temporal Extent: 2017-10-21 - 2018-10-14

Methods & Sampling

Field sampling

Galveston Bay is a semi-enclosed microtidal estuary located in the nwGOM [42]. With an average water depth of 3 m and surface area covering 1554 km2, Galveston Bay is the seventh largest estuary in the U.S. and the second largest estuary on the Texas coast [35, 43, 44]. Galveston Bay receives freshwater from the Trinity River, San Jacinto River, Clear Creek, and smaller bayous and creeks, with the Trinity River providing 70% of the freshwater entering the Bay [35, 45, 43, 44]. The Bolivar Peninsula and Galveston Island separate Galveston Bay from the GOM, with exchange of water between the Bay and the GOM occurring through Bolivar Roads, i.e., the mouth of the Bay [46, 43].

Monthly cruises were conducted between October 2017 and September 2018 on board the *R/V* Trident. Timing of the study allowed for examination of the factors regulating CO2 flux over the course of a year following Hurricane Harvey in late August of 2017. Although the study began more than 45 days (the residence time of the Bay) after Harvey, salinity recovery of the Bay was likely still ongoing in the inner and middle sections of the Bay [47, 48].

During each monthly survey, a transect was run between five water sampling stations, extending northwest from the Bay mouth (Station 1) opening to the Five Mile Marker on the Houston Ship Channel (Station 5). One offshore cruise in the nwGOM outside Galveston Bay was conducted in October of 2018. Underway *p*CO2 measurements were taken along a northwesterly transect extending from stations 1 through 5. A SUPER-CO2 System equipped with a LI-COR® LI-840A infrared gas analyzer was used to collect both water and air *x*CO2 after drying through a Peltier thermoelectric device, and the *x*CO2 data after removing residual water vapor [49] was converted to *p*CO2 at sea surface temperature assuming 100% water vapor pressure [50]. Underway seawater was taken from a steel pipe attached to the side of the research vessel as it did not have a dedicated water intake system, and a diaphragm water pump was used to feed water to the equilibrator. In situ sea surface temperature and salinity were measured with a SeaBird Scientific SBE45® Thermosalinograph that was mounted parallel to the equilibrator of the SUPER-CO2 System. Prior to and following each sampling trip, the SUPER-CO2 System was calibrated using standards of known CO2 concentrations (273.3, 774.3, and 1468.7 ppm).

To calculate the *p*CO2 of seawater and air from measurements, the measured mole fraction of CO2 in seawater (*x*CO2, water) and measured equilibrator barometric pressure and *x*H2O were first used to calculate *x*CO2 in dry air (*x*CO2, air). This *x*CO2, air was then converted to *p*CO2 of equilibration (*p*CO2, eq) using measured temperature of equilibration (Teq) and water vapor pressure of equilibration, which was calculated from salinity and Teq according to methods outlined in [51]. Next, sea surface temperature (SST) and Teq were used to convert *p*CO2, eq to *p*CO2, water according to [52]. For *p*CO2, air, *x*CO2, air was converted to *p*CO2, air using water vapor pressure at SST and salinity, assuming 100% humidity [51].

Meteorological data

Three National Oceanic and Atmospheric Administration (NOAA) buoys from throughout Galveston Bay [60] provided six-minute interval averages of continuous wind speed data. The average wind speed for all three buoys during sampling times was calculated and applied to timing of sampling in Galveston Bay. Prior to calculations, wind speeds were converted to a height of 10 m (*u*10) using the wind profile power law [61],

u1/u2 = (z1/z2)^P

where *u2* is wind speed at height *z2* = 10 m, *u1* is the collected wind speed data at height *z1*, and the exponent *P* (0.11) around GOM area is extracted by [61].

United States Geological Survey [62] streamgages for the Trinity River (gage #08066500) and San Jacinto River, east fork (SJE; gage #08070200) and west fork (SJW; gage #08068000) were used to obtain freshwater discharge. These stations were identified as the closest gages to the mouths of the rivers having complete discharge data for the period of study. Discharges of less than or equal to 45 days (residence time of the Bay) prior to flux estimates were utilized [43, 44]. The Texas Commission on Environmental Quality (TCEQ) performs routine water quality monitoring, and TCEQ water sampling stations were used for river endmember values from the San Jacinto (average of west fork station #11243 and east fork station #11238) and Trinity (station # 10896) rivers [63]. River endmember DIC was calculated from TA and pH measurements using *K1* and *K2* constants from Millero [64], and pH value on the NBS scale. Seasonally weighted averages were calculated by summing the TA or DIC concentration multiplied by daily discharge values for all river measurements of that season and dividing by the sum of all discharge values for all river measurements of that season (using meteorological seasons).

Historical data

Results from this study were compared to historical data for Galveston Bay obtained from the Surface Ocean

CO2Atlas (SOCAT) database [80], which provided *f*CO2, water and *x*CO2, air values, along with surface seawater salinity, temperature, and depth, with observations from 2006 and 2010 through 2016, primarily during the month of September. SOCAT transects followed a similar route to our study transect, beginning near to station 4 and continuing outward into the GOM, with a side transect through the Galveston Channel, which separates Pelican Island from Galveston Island. *f*CO2 values were converted to *p*CO2 using the R package *seacarb* [81]. SOCAT data were analyzed independently from the results of this study. As done before with ship data, SOCAT *x*CO2, air was converted to *p*CO2, air by accounting for water vapor pressure based on SST and SSS, assuming 100% humidity [74].

Data Processing Description

Air-water CO2 flux calculation

Air-water Prior to calculations of CO2 flux based on in situ measurements, outliers were identified graphically and removed from final datasets. Air-water CO2 flux was calculated using Eq. 3,

F = kK0(pCO2,water - pCO2,air) (3)

where *k* (m d-1) is the gas transfer velocity calculated from wind speed and *K0* (mol m-3 atm-1) is the gas solubility at measured in situ temperature and salinity [73].

Gas transfer velocity (piston velocity) at Schmidt number of 600 and referenced to wind speed at 10 m above the sea surface was calculated and compared for consistency using several methods [74, 50, 75, 76]. Ultimately the equation from Jiang et al. [50], which was meant for estuaries and allows for wind speeds up to 12 m s-1, was chosen as the most appropriate for calculating gas transfer velocity within the study area [34],

k = (0.314 x u10^2 - 0.436 x u10 + 3.990) x (ScSST/600)^-0.5. (4)

where *u*10 is the wind speed referenced at 10 m above the water surface (m s-2) and *ScSST* is the Schmidt number of CO2 at in situ temperature, calculated for seawater according to [77].

To assess the best calculation method, air-sea CO2 flux, sea surface *p*CO2, temperature, salinity, wind speed, and atmospheric pressure were averaged over 0.01^{o} and 0.025^{o} latitude increments and values were used to calculate flux in two separate analyses. When a two-tailed Student's *t*-test was conducted, CO2 flux calculations did not significantly differ between the two groupings for any of the sampling months ($p \geq 0.50$ for all sampling months). For all further analyses, CO2 flux was calculated based on the larger 0.025^{o} latitude increments, which simplified calculations.

Linear interpolation between adjacent months was used to quantify CO2 flux, salinity, temperature, *p*CO2, air, and *p*CO2, water in sampling months where values were missing for some of the latitudinal increments [50]. Missing values for monthly atmospheric *p*CO2 were also calculated based on linear interpolation. Seasonal values were determined by averaging monthly CO2 flux estimates by season, where fall included September, October, and November, winter included December, January, and February, spring included March, April, and May, and summer included June, July, and August measurements. Resultant *p*CO2, water and SSS from underway measurements was compared to *p*CO2, water calculated from pH and DIC measured from discrete samples and SSS from discrete samples. *p*CO2 is strongly influenced by temperature [78]; therefore, to allow analyses of *p*CO2 changes due to other causes than temperature (e.g., photosynthesis, respiration, etc.), thermally-adjusted water *p*CO2 was calculated according to equation 1 from Takahashi [79].

Statistical analyses

Since Galveston Bay is located immediately adjacent to the urban Houston and Galveston metroplex, local emission may lead to high localized atmospheric CO2 levels, which could depend on wind speed and direction. To determine the influence of wind speed (*u*10) and direction on *p*CO2, air, Pearson's correlation coefficients with *p*-values were calculated for each variable and *p*CO2, air. Predictor variables for which Pearson's correlation *p*-value was <0.05 and the absolute correlation coefficient value was >0.7 were designated as significantly correlated to *p*CO2, air.

Due to non-normality of data and non-homogeneity of variances, Kruskal-Wallis nonparametric Analysis of Variance (ANOVA) tests [82] were performed in R to compare carbonate system parameters (DIC, TA, pH, and ΩAr) between season and stations. Further exploration of values was done via Dunn tests, which test for individual differences between each pair of groups when nonparametric data are used [82].

To fully assess the influences of biogeochemistry on *p*CO2, several multiple linear regression models were compared based on residuals, *R2* values, and significance. Initial possible predictor variables for the discrepancy in *p*CO2between calculated and underway measured values (calculated – measured, or d*p*CO2) included difference in salinity between discrete and measured values, discrete salinity measurements, SST, DIC, TA, ΩAr, and pHT, of which all but salinity difference and SST remained in the final chosen model.

Problem Description

Gaps in sampling were filled with linear interpolation.

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Related Publications

Bass, B., Torres, J. M., Irza, J. N., Proft, J., Sebastian, A., Dawson, C., & Bedient, P. (2018). Surge dynamics across a complex bay coastline, Galveston Bay, TX. Coastal Engineering, 138, 165–183. https://doi.org/10.1016/j.coastaleng.2018.04.019
Methods

Dellapenna, T. M., Hoelscher, C., Hill, L., Al Mukaimi, M. E., & Knap, A. (2020). How tropical cyclone flooding caused erosion and dispersal of mercury-contaminated sediment in an urban estuary: The impact of Hurricane Harvey on Buffalo Bayou and the San Jacinto Estuary, Galveston Bay, USA. Science of The Total Environment, 748, 141226. https://doi.org/10.1016/j.scitotenv.2020.141226
Methods

Du, J., & Park, K. (2019). Estuarine salinity recovery from an extreme precipitation event: Hurricane Harvey in Galveston Bay. Science of The Total Environment, 670, 1049–1059. https://doi.org/10.1016/j.scitotenv.2019.03.265
Methods

Du, J., Park, K., Dellapenna, T. M., & Clay, J. M. (2019). Dramatic hydrodynamic and sedimentary responses in Galveston Bay and adjacent inner shelf to Hurricane Harvey. Science of The Total Environment, 653, 554–564. https://doi.org/10.1016/j.scitotenv.2018.10.403
Methods

Glass, L. A., Rooker, J. R., Kraus, R. T., & Holt, G. J. (2008). Distribution, condition, and growth of newly settled southern flounder (Paralichthys lethostigma) in the Galveston Bay Estuary, TX. Journal of Sea Research, 59(4), 259–268. https://doi.org/10.1016/j.seares.2008.02.006
Methods

Montagna, P. A., Palmer, T. A., & Beseres Pollack, J. (2013). Hydrological Changes and Estuarine Dynamics. In SpringerBriefs in Environmental Science. Springer New York. https://doi.org/10.1007/978-1-4614-5833-3
Methods

Morse, J. W., Presley, B. J., Taylor, R. J., Benoit, G., & Santschi, P. (1993). Trace metal chemistry of Galveston Bay: water, sediments and biota. Marine Environmental Research, 36(1), 1–37. https://doi.org/10.1016/0141-1136(93)90087-g https://doi.org/10.1016/0141-1136(93)90087-G
Methods

Solis, R. S., & Powell, G. L. (1999). Hydrography, mixing characteristics, and residence times of Gulf of Mexico estuaries. In T. S. Bianchi, J. R. Pennock, & R. R. Twilley (Eds.), Biogeochemistry of Gulf of Mexico estuaries (pp. 29–62). New York, NY: John Wiley & Sons.
Methods

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Parameters

Parameters for this dataset have not yet been identified

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Project Information

RAPID: Capturing the Signature of Hurricane Harvey on Texas Coastal Lagoons (Hurricane Harvey Texas Lagoons)

Coverage: Northwest Gulf of Mexico estuaries on Texas Coast

NSF Award Abstract:
Hurricane Harvey made landfall Friday 25 August 2017 about 30 miles northeast of Corpus Christi, Texas as a Category 4 hurricane with winds up to 130 mph. This is the strongest hurricane to hit the middle Texas coast since Carla in 1961. After the wind storm and storm surge, coastal flooding occurred due to the storm lingering over Texas for four more days, dumping as much as 50 inches of rain near Houston. This will produce one of the largest floods ever to hit the Texas coast, and it is estimated that the flood will be a one in a thousand year event. The Texas coast is characterized by lagoons behind barrier islands, and their ecology and biogeochemistry are strongly influenced by coastal hydrology. Because this coastline is dominated by open water systems and productivity is driven by the amount of freshwater inflow, Hurricane Harvey represents a massive inflow event that will likely cause tremendous changes to the coastal environments. Therefore, questions arise regarding how biogeochemical cycles of carbon, nutrients, and oxygen will be altered, whether massive phytoplankton blooms will occur, whether estuarine species will die when these systems turn into lakes, and how long recovery will take? The investigators are uniquely situated to mount this study not only because of their location, just south of the path of the storm, but most importantly because the lead investigator has conducted sampling of these bays regularly for the past thirty years, providing a tremendous context in which to interpret the new data gathered. The knowledge gained from this study will provide a broader understanding of the effects of similar high intensity rainfall events, which are expected to increase in frequency and/or intensity in the future.

The primary research hypothesis is that: Increased inflows to estuaries will cause increased loads of inorganic and organic matter, which will in turn drive primary production and biological responses, and at the same time significantly enhance respiration of coastal blue carbon. A secondary hypothesis is that: The large change in salinity and dissolved oxygen deficits will kill or stress many estuarine and marine organisms. To test these hypotheses it is necessary to measure the temporal change in key indicators of biogeochemical processes, and biodiversity shifts. Thus, changes to the carbon, nitrogen and oxygen cycles, and the diversity of benthic organisms will be measured and compared to existing baselines. The PIs propose to sample the Lavaca-Colorado, Guadalupe, Nueces, and Laguna Madre estuaries as follows: 1) continuous sampling (via autonomous instruments) of salinity, temperature, pH, dissolved oxygen, and depth (i.e. tidal elevation); 2) bi-weekly to monthly sampling for dissolved and total organic carbon and organic nitrogen, carbonate system parameters, nutrients, and phytoplankton community composition; 3) quarterly measurements of sediment characteristics and benthic infauna. The project will support two graduate students. The PIs will communicate results to the public and to state agencies through existing collaborations.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1760006

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