

Houston Galveston Bay pCO₂

Website: <https://www.bco-dmo.org/dataset/949729>

Data Type: Cruise Results

Version: 1

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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. CO₂ flux 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 pCO₂ was 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

Temporal Extent: 2017-10-21 - 2018-10-15

Dataset Description

File naming convention notes:

1. Calibration files:

See the "Supplemental Files" section of this dataset to access calibration files.

- Standard calibrations title format: "standardMMDDYYYY_pCO2_notes_mmddhhhh.txt", where MMDDYYYY is the month, date, and year of sample collection, and mmddhhhh is the month, date, and hour of data processing in local time.
- Pre-sampling calibrations title format: "precalibrationMMDDYYYY_pCO2_notes_mmddhhhh.txt", where MMDDYYYY is the month, date, and year of sample collection, and mmddhhhh is the month, date, and hour of data processing in local time.
- Post-sampling calibrations title format: "postcalibrationMMDDYYYY_pCO2_notes_mmddhhhh.txt", where MMDDYYYY is the month, date, and year of sample collection, and mmddhhhh is the month, date, and hour of data processing in local time.

2. In situ notes files:

See the "Supplemental Files" section of this dataset to access notes files.

- "GB_pCO2_MMDDYYYY_pCO2_notes_mmddhhhh.txt", where MMDDYYYY is the month, date, and year of sample collection and mmddhhhh is the month, date, and hour of notes.

3. Data files

The original files (.txts) have been merged into one file, which is the primary data file of this dataset (949729_v1_houston_galveston_bay_pco2). The original filenames can be found in the Source_File column of this primary data file.

- GB_pCO2_MMDDYYYY_pCO2_mmddhhhh.txt", where MMDDYYYY is the month, date, and year of sample collection and mmddhhhh is the month, date, and hour of data processing.

Methods & Sampling

Field Sampling

Galveston Bay is a semi-enclosed microtidal estuary located in the northwestern Gulf of Mexico (nwGOM) (Montagna, Palmer, & Pollack, 2013). With an average water depth of 3 m and a surface area of 1554 km², Galveston Bay is the seventh largest estuary in the U.S. and the second largest estuary on the Texas coast (Bass, Torres, Irza, Proft, Sebastian, Dawson, Bedient, 2018; Morse et al., 1993; Solis & Powell, 1999). 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 (Bass et al., 2018; Morse et al., 1993; Solis & Powell, 1999). The Bolivar Peninsula and Galveston Island separate Galveston Bay from the Gulf of Mexico (GOM), with exchange of water between the Bay and the GOM occurring through Bolivar Roads, the mouth of the Bay (Glass, Rooker, Kraus, & Holt, 2008).

Monthly cruises were conducted between October 2017 and September 2018 aboard the R/V *Trident*. The 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 2017. Although the study began more than 45 days after the hurricane (the residence time of the Bay), salinity recovery of the Bay was likely still ongoing in the inner and middle sections (Du & Park, 2019; Du, Park, Dellapenna, & Clay, 2019).

During each monthly survey, a transect was run between five water sampling stations, extending northwest from the Bay mouth (Station 1) 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 2018. Underway pCO₂ measurements were taken along a northwesterly transect 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 xCO₂ after drying through a Peltier thermoelectric device. The xCO₂ data, after removing residual water vapor (Honkanen et al., 2021), was converted to pCO₂ at sea surface temperature assuming 100% water vapor pressure (Jiang et al., 2008). 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 (SST) and salinity were measured with a SeaBird Scientific SBE45® Thermosalinograph 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 pCO₂ of seawater and air from measurements, the measured mole fraction of CO₂ in seawater (xCO₂, water) and measured equilibrator barometric pressure and xH₂O were first used to calculate xCO₂ in dry air (xCO₂, air). This xCO₂, air was then converted to pCO₂ of equilibration (pCO₂, eq) using measured temperature of equilibration (T_{eq}) and water vapor pressure of equilibration, which was calculated from salinity and T_{eq} according to methods outlined in Weiss and Price (1980). Next, SST and T_{eq} were used to convert pCO₂, eq to pCO₂, water (Weiss & Price, 1980). For pCO₂, air, xCO₂, air was converted to pCO₂, air using water vapor pressure at SST and salinity, assuming 100% humidity (Borges et al., 2004).

Meteorological Data

Three National Oceanic and Atmospheric Administration (NOAA) buoys from throughout Galveston Bay provided six-minute interval averages of continuous wind speed data (NOAA, 2022). The average wind speed for all three buoys during sampling times was calculated and applied to the timing of sampling in Galveston Bay. Prior to calculations, wind speeds were converted to a height of 10 m (u₁₀) using the wind profile power law (Hsu, Meindl, & Gilhousen, 1994):

$$u_1/u_2 = (z_1/z_2)^P$$

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 the GOM area is extracted by Hsu et al. (1994).

United States Geological Survey (USGS) 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 (USGS, 2021). 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 (Bass et al., 2018; Morse et al., 1993). 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 (TCEQ, 2022). River endmember DIC was calculated from TA and pH measurements using K₁ and K₂ constants from Millero (1980), and pH values 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 CO₂ Atlas (SOCAT) database, which provided fCO₂, water and xCO₂, air values, along with surface seawater salinity, temperature, and depth, with observations from 2006 and 2010 through 2016, primarily during the month of September (Bakker et al., 2016). SOCAT transects followed a similar route to our study transect, beginning near Station 4 and continuing outward into the GOM, with a side transect through the Galveston Channel, which separates Pelican Island from Galveston Island. fCO₂ values were converted to pCO₂ using the R package *seacarb* (Gattuso et al., 2022). SOCAT data were analyzed independently from the results of this study. As done previously with ship data, SOCAT xCO₂, air was converted to pCO₂, air by accounting for water vapor pressure based on SST and SSS, assuming 100% humidity (Borges et al., 2004).

Data Processing Description

Air-water CO₂ Flux Calculation

Prior to calculating CO₂ flux based on in situ measurements, outliers were identified graphically and removed from the final datasets. Air-water CO₂ flux was calculated using the following equation:

$$F = k * K_0 * (pCO_{2,water} - pCO_{2,air})$$

Where:

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

Gas transfer velocity (piston velocity) at a Schmidt number of 600, referenced to wind speed at 10 m above

the sea surface, was calculated and compared for consistency using several methods. Ultimately, the equation from Jiang et al. (2008), which was designed for estuaries and allows for wind speeds up to 12 m/s, was chosen as the most appropriate for calculating gas transfer velocity within the study area:

$$k = (0.314 * u_{10}^2 - 0.436 * u_{10} + 3.990) * (Sc_{SST}/600)^{-0.5}$$

Where:

- u_{10} is the wind speed at 10 m above the water surface (m/s),
- Sc_{SST} is the Schmidt number of CO₂ at in situ temperature, calculated for seawater.

To assess the best calculation method, air-sea CO₂ flux, sea surface pCO₂, temperature, salinity, wind speed, and atmospheric pressure were averaged over 0.01° and 0.025° latitude increments, and values were used to calculate flux in two separate analyses. A two-tailed Student's t-test showed that CO₂ flux calculations did not significantly differ between the two groupings for any of the sampling months ($p \geq 0.50$ for all months). For all further analyses, CO₂ flux was calculated based on the larger 0.025° latitude increments to simplify calculations.

Linear interpolation between adjacent months was used to estimate CO₂ flux, salinity, temperature, pCO₂, air, and pCO₂, water during months where values were missing for some of the latitudinal increments. Missing values for monthly atmospheric pCO₂ were also calculated using linear interpolation. Seasonal values were determined by averaging monthly CO₂ flux estimates by season, with fall including September, October, and November; winter including December, January, and February; spring including March, April, and May; and summer including June, July, and August measurements.

Resulting pCO₂, water and sea surface salinity (SSS) from underway measurements were compared to pCO₂, water calculated from pH and DIC measured from discrete samples and SSS from discrete samples. Since pCO₂ is strongly influenced by temperature, thermally-adjusted water pCO₂ was calculated according to the equation from Takahashi [79] to assess changes in pCO₂ due to factors other than temperature (e.g., photosynthesis, respiration).

Statistical Analyses

Galveston Bay, located adjacent to the urban Houston and Galveston metroplex, may experience high localized atmospheric CO₂ levels due to local emissions, which could depend on wind speed and direction. To determine the influence of wind speed (u_{10}) and direction on pCO₂, air, Pearson's correlation coefficients with p-values were calculated for each variable and pCO₂, air. Predictor variables with a Pearson's correlation p-value <0.05 and an absolute correlation coefficient value >0.7 were designated as significantly correlated to pCO₂, air.

Due to non-normality of data and non-homogeneity of variances, Kruskal-Wallis nonparametric Analysis of Variance (ANOVA) tests were performed in R to compare carbonate system parameters (DIC, TA, pH, and Ω_{Ar}) across seasons and stations. Further exploration of values was conducted using Dunn tests, which assess individual differences between each pair of groups when nonparametric data are used.

To fully assess the influences of biogeochemistry on pCO₂, several multiple linear regression models were compared based on residuals, R² values, and significance. Initial potential predictor variables for the discrepancy in pCO₂ between calculated and underway measured values (calculated - measured, or $dpCO_2$) included the difference in salinity between discrete and measured values, discrete salinity measurements, SST, DIC, TA, Ω_{Ar} , and pHT. All but salinity difference and SST remained in the final chosen model.

BCO-DMO Processing Description

- Merged all of the raw pCO₂ data (txt) files into one CSV file, which is the primary data file for this dataset.
- Added a datetime column to the primary datafile from the Date and Time columns in the primary data file. This new column is called ISO_DateTime_UTC.
- All of the related calibration and note files for this dataset are served as supplemental files.
- Special characters were removed from the column names within the primary data file.
- Column "820pwrV" renamed to "Voltage_output_820pwrV."

Problem Description

Gaps in sampling were filled with linear interpolation.

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Related Publications

American Meteorological Society. (1994). Determining the planetary temperature profile from limb-viewing passive remote sensors. *Journal of Applied Meteorology and Climatology*, 33(6), 757–775. Retrieved from https://journals.ametsoc.org/view/journals/apme/33/6/1520-0450_1994_033_0757_dtplwp_2_0_co_2.xml
[https://doi.org/doi.org/10.1175/1520-0450\(1994\)033<0757:DTPLWP>2.0.CO;2](https://doi.org/doi.org/10.1175/1520-0450(1994)033<0757:DTPLWP>2.0.CO;2)

Methods

Bakker, D. C. E., Pfeil, B., Landa, C. S., Metzl, N., O'Brien, K. M., Olsen, A., Smith, K., Cosca, C., Harasawa, S., Jones, S. D., Nakaoka, S., Nojiri, Y., Schuster, U., Steinhoff, T., Sweeney, C., Takahashi, T., Tilbrook, B., Wada, C., Wanninkhof, R., Xu, S. (2016). A multi-decade record of high-quality fCO₂ data in version 3 of the Surface Ocean CO₂ Atlas (SOCAT). *Earth System Science Data*, 8(2), 383–413. <https://doi.org/10.5194/essd-8-383-2016>

References

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

Borges, A. V., Delille, B., Schiettecatte, L., Gazeau, F., Abril, G., & Frankignoulle, M. (2004). Gas transfer velocities of CO₂ in three European estuaries (Randers Fjord, Scheldt, and Thames). *Limnology and Oceanography*, 49(5), 1630–1641. Portico. <https://doi.org/10.4319/lo.2004.49.5.1630>

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

Honkanen, M., Müller, J. D., Seppälä, J., Rehder, G., Kielosto, S., Ylöstalo, P., Mäkelä, T., Hatakka, J., & Laakso, L. (2021). The diurnal cycle of pCO₂ in the coastal region of the Baltic Sea. *Ocean Science*, 17(6), 1657–1675. <https://doi.org/10.5194/os-17-1657-2021>

Methods

Jiang, L., Cai, W., Wanninkhof, R., Wang, Y., & Lüger, H. (2008). Air-sea CO₂ fluxes on the U.S. South Atlantic Bight: Spatial and seasonal variability. *Journal of Geophysical Research: Oceans*, 113(C7). Portico. <https://doi.org/10.1029/2007jc004366>
<https://doi.org/10.1029/2007JC004366>

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)
[https://doi.org/10.1016/0141-1136\(93\)90087-G](https://doi.org/10.1016/0141-1136(93)90087-G)

Methods

Raymond, P. A., & Cole, J. J. (2001). Gas Exchange in Rivers and Estuaries: Choosing a Gas Transfer Velocity. *Estuaries*, 24(2), 312. <https://doi.org/10.2307/1352954>

Methods

Ruxton, G. D., & Beauchamp, G. (2008). Some suggestions about appropriate use of the Kruskal-Wallis test. *Animal Behaviour*, 76(3), 1083–1087. <https://doi.org/10.1016/j.anbehav.2008.04.011>

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

Summary for Policymakers. (2014). *Climate Change 2013 – The Physical Science Basis*, 1–30.

<https://doi.org/10.1017/cbo9781107415324.004> <https://doi.org/10.1017/CBO9781107415324.004>

Methods

Wanninkhof, R., Asher, W. E., Ho, D. T., Sweeney, C., & McGillis, W. R. (2009). Advances in Quantifying Air-Sea Gas Exchange and Environmental Forcing. *Annual Review of Marine Science*, 1(1), 213–244.

<https://doi.org/10.1146/annurev.marine.010908.163742>

Methods

Weiss, R. F. (1974). Carbon dioxide in water and seawater: the solubility of a non-ideal gas. *Marine Chemistry*, 2(3), 203–215. doi:[10.1016/0304-4203\(74\)90015-2](https://doi.org/10.1016/0304-4203(74)90015-2)

Methods

Yao, H., & Hu, X. (2017). Responses of carbonate system and CO₂ flux to extended drought and intense flooding in a semiarid subtropical estuary. *Limnology and Oceanography*, 62(S1). Portico.

<https://doi.org/10.1002/lno.10646>

Methods

Zeebe, R. E., & Wolf-Gladrow, D. (2001). CO₂ in seawater: equilibrium, kinetics, isotopes (No. 65). Gulf Professional Publishing. <https://isbnsearch.org/isbn/978-0444509468>

Methods

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Parameters

Parameters for this dataset have not yet been identified

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Instruments

Dataset-specific Instrument Name	SUPER-CO ₂ System
Generic Instrument Name	CO ₂ Analyzer
Dataset-specific Description	A SUPER-CO ₂ System equipped with a LI-COR LI-840A infrared gas analyzer was used to analyze both water and air xCO ₂ after drying through a Peltier thermoelectric device.
Generic Instrument Description	Measures atmospheric carbon dioxide (CO ₂) concentration.

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Deployments

Galveston_Bay_Cruises

Website	https://www.bco-dmo.org/deployment/949750
Platform	R/V Trident
Start Date	2017-10-21
End Date	2018-10-14

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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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