Galveston Bay

The Effects of Freshwater Inflow on Water Temperature

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Introduction

In January of 2012, the Hodges group became involved in a project funded by the Gulf of Mexico Research Initiative (GoMRI). This project will include taking field measurements in several bays along the U.S. coast of the Gulf of Mexico. These measurements will include water velocity, conductivity, temperature, etc. with the end goal of understanding the flow in the bays and creating a model capable of predicting the flow as well as how an oil spill would propagate in the bays. The first bay of interest is Galveston Bay near Houston, TX. This bay was given first priority because of its higher "political" implications (people are worried about another Hurricane Ike) when compared to the other bays to be studied (Corpus Christi Bay, TX and Barataria Bay, LA). Although the group's particular role in the project does not include any of the modeling of the bay, it would be beneficial to understand the inflows into Galveston Bay and how they affect the flow in the entire bay.

Galveston Bay is located in southeastern Texas, about 20 miles southeast of Houston. The bay has two main freshwater inflows: the San Jacinto River flowing in from the northwest and the Trinity River flowing from the north. The Trinity River is the main freshwater source in the system, with a mean daily discharge of 6620 cubic feet per second (cfs) (USGS). The San Jacinto is much smaller, having a mean daily discharge of 372 cfs (USGS). A map of the area can be seen below in Figure 1. As can be inferred from the elevation map, a ship channel bisects the bay, running from the mouth of the San Jacinto River southeastward to where Galveston Bay meets the Gulf of Mexico. With the exception of the 15-meter-deep ship channel, the bay is fairly consistent in terms of depth, ranging from 0.5 meters to 5 meters.

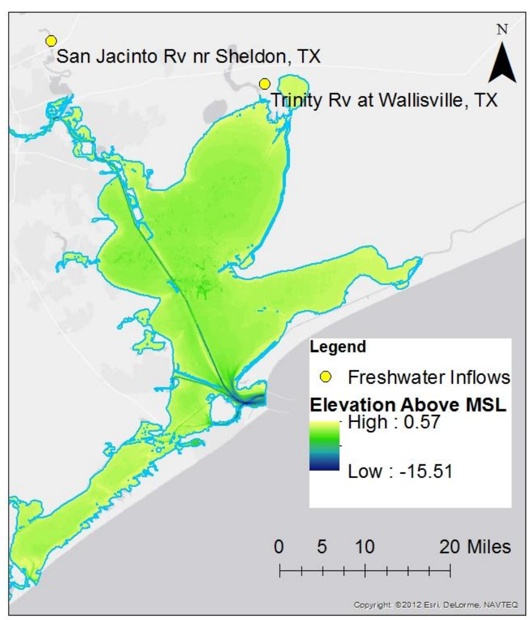

Figure 1: A map showing the layout of Galveston Bay in terms of Elevation above Mean Sea Level. 30 m DEM obtained from NOAA Estuarine Bathymetry.

Available Data

In order to begin a study on an area, one must have data for that area. The National Oceanic and Atmospheric Association (NOAA) maintains a dataset of hundreds of buoys worldwide known as the National Data Buoy Center (NDBC). This dataset includes meteorological and oceanographic data for many sites, including 7 near Galveston Bay. The sights near Galveston Bay provided only one oceanographic variable, water temperature. Buoy data in other locations provided salinity as well, which would have been very helpful to this research. However, with just water temperature available, there is still a chance of gleaning something useful from this research. Shown below in Figure 2 are the spatial locations available through the NDBC for Galveston Bay.

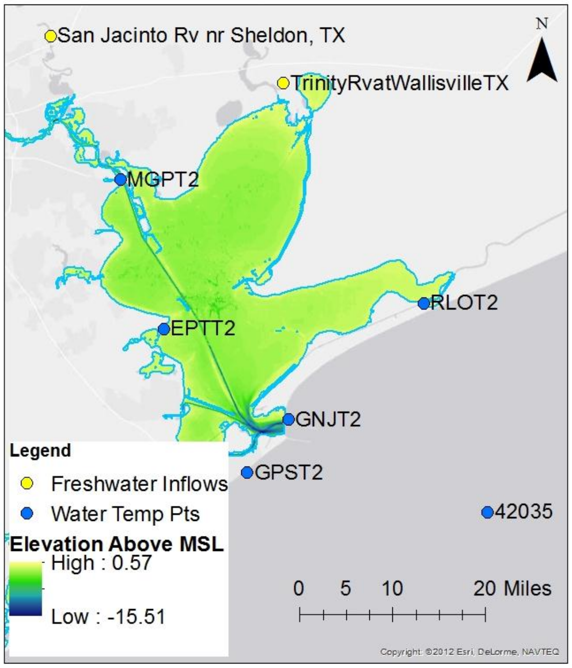

Figure 2: A map showing the NOAA NDBC data points available for Galveston Bay.

In addition to data within the bay, it was necessary to find information about the freshwater inflows, as well. Using the U.S. Geological Survey (USGS) tool, WaterWatch, the gauge heights of the two main freshwater inflows for Galveston Bay were obtained. Similarly to the NDBC data, another measurement of flow, perhaps discharge, would have been more helpful for this project. Unfortunately, only height above gauge was available for the USGS gauging stations closest to the bay. The closest gauging station with stream discharge data for the San Jacinto River was upstream of Lake Houston, a reservoir on the San Jacinto upstream of Galveston Bay. Because it is a reservoir, it was decided that streamflow data for a point upstream of Lake Houston would not be representative of the actual flow into the bay itself. For the Trinity River, the nearest gauging station to Galveston Bay was near Goodrich, TX. This location is upstream of several lakes that drain into the Trinity River near its mouth in Galveston Bay, and therefore was also deemed unrepresentative of the actual freshwater inflow from the Trinity River into Galveston Bay. It was for these reasons that the data from USGS gauging stations on the San Jacinto near Sheldon, TX and on the Trinity River at Wallisville, TX were used, even though they only provided height above gauge information.

Taking into consideration the data available, it was decided that a relationship between freshwater inflow and water temperature in the bay might be discernable. The most complete year of water temperature data available was 2011, so this became the year of focus for this project. Looking at height above gauge data for 2011 at both gauging stations, an interesting trend became obvious. As can be seen in Figure 3 below, the two graphs are almost identical. Because of this phenomenon, it was decided that a comparison of a period of high inflow (indicated by large heights above gauge) to a period of low inflow (indicated by small heights above gauge) might yield some interesting results. A high-inflow period of October 3rd to October 16th (indicated by the solid black boxes in Figure 3) and a low-inflow period of January 27th to February 9th (indicated by the dashed black boxes in Figure 3) were chosen. The indicated low-inflow period was chosen over the lower gauge height period seen in early September 2011 because of its consistently lower values.

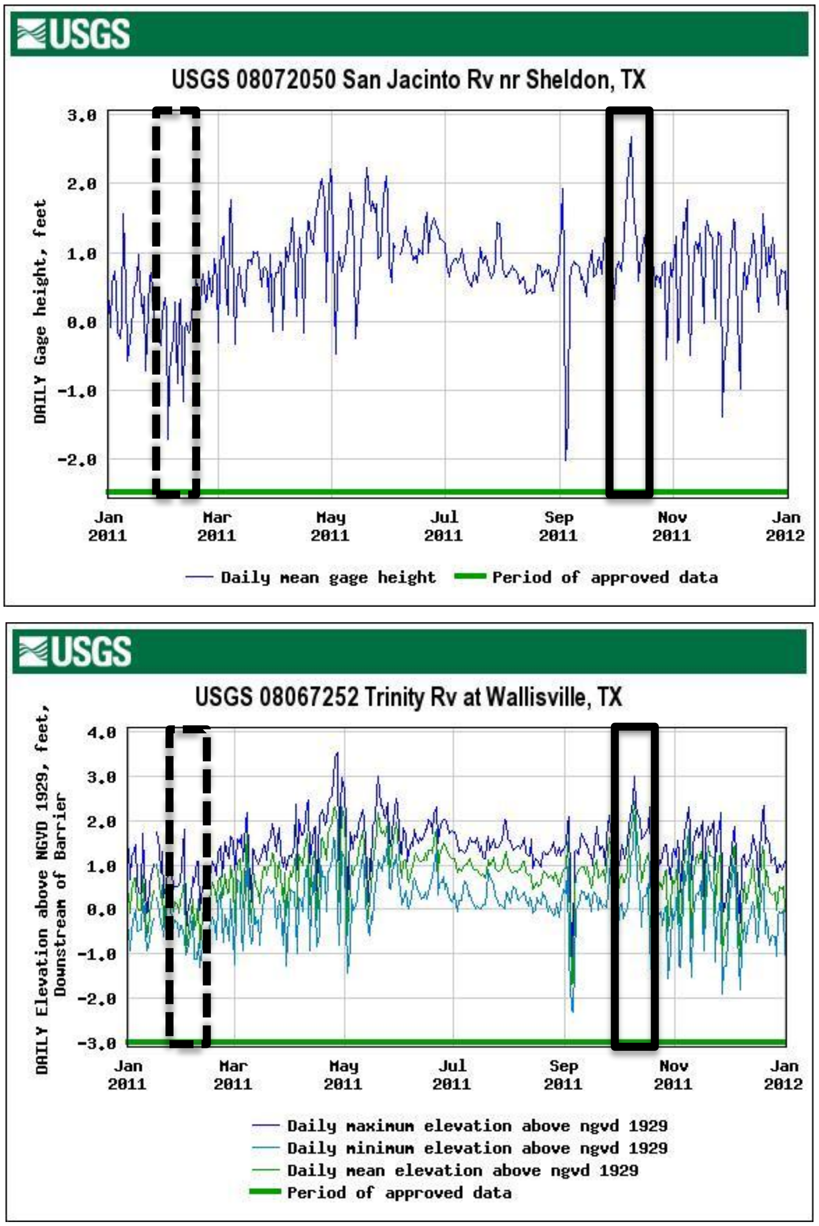

Figure 3: Height above Gauge values for USGS gauging stations 08072050 (top) and 08067252 (bottom) for 2011. Boxes indicate periods of interest for this study.

Methods

Once the objective of the project became clear, all that was left was to visualize the data using GIS, or more specifically, ArcMap 10.1. Before using ArcMap, though, the data needed to be transformed into a workable format. For example, the water temperature data from the NDBC was reported in either 6-minute or hourly intervals. For this study, it was desired to work with daily changes in water temperature, so the data was imported into Matlab to create daily average values for each day being studied. Once this step was accomplished, the data were organized into two tables using Excel: one for the period of high inflow and one for the period of low inflow. Each table contained a daily water temperature value for each day in the 2-week time period for each point in Galveston Bay. These Excel tables were then imported into ArcMap 10.1, and analysis was able to commence. An example of one of these tables in ArcMap can be seen in FIGURE below.

FID	Shape *	ID	Water_Temp	Latitude	Longitude	WT012711	WT012811	WT012911	WT01
0	Point	1	MGPT2	29.682	-94.985	11.482083	11.756667	11.995	12
1	Point	2	EPTT2	29.48	-94.918	11.675104	12.058506	13.029876	14.1
2	Point	5	GPST2	29.285	-94.788	12.27	12.431667	13.102917	13.5
3	Point	6	42035	29.232	-94.413	12.904167	12.0375	12.429167	12.8
4	Point	8	TrinityRvatWallisvilleTX	29.812222	-94.731111	10.2	10.4	11.1	

Figure 4: Example of attribute tables used in analysis. Each row represents a spatial data point and each column represents one day of data at each point.

In order to represent water temperature values for everywhere in Galveston Bay and not just at the measurement points, an interpolation was performed. Using the Spline tool in the Spatial Analyst Toolbox of ArcMap 10.1, a smoothly interpolated raster image representing water temperature was created that covered nearly the entire bay. The Spline tool was chosen because it produces the smoothest interpolations, meaning that there are no sharp transitions anywhere in the interpolation. This seemed to be the ideal tool for interpolating water temperatures, as they tend to have a very smooth gradient from one location to another.

The raster produced by the Spline tool not only interpolated water temperatures for Galveston Bay, but, because of the locations of the data points used, also included some land areas surrounding the bay, as well. To create a raster that only showed water temperature points for locations within the bay, it was first necessary to find a GIS shapefile that represented the boundary of the bay. Fortunately, a short search led to NOAA's Estuarine Bathymetry webpage, which contained a digital elevation model (DEM) and a shapefile for the boundary of many bays along the U.S. coasts. These files are the product of many years of research conducted by the National Ocean Service (NOS), a branch of NOAA. The DEM for Galveston Bay is seen in Figure 1. More importantly, though, once the boundary shapefile was downloaded it made it possible to create a raster interpolation of only those water temperature values that fell within the boundary of the bay. Using this method for each day that was studied, 28 images were created (14 for the high inflow period and 14 for the low inflow period).

Results & Discussion

With the images created, an analysis of the images and an attempt to discern any obvious relationships was undertaken. To simplify the identification of any patterns, a .GIF movie was created for each of the 14-day time periods using a software package called Photoscape. A link to these .GIF files can be found at https://www.dropbox.com/sh/2u1rtigl9zdgs5g/0I3QvDLX8j. Looking at the low freshwater inflow period, a warming trend can be seen in the days leading up to the low point on 02/02. After the low point, the overall water temperature of the bay drops significantly before beginning to warm slowly again. This trend seems counterintuitive. A low inflow event should have almost no impact on the system, because very little freshwater is being discharged into the bay. This "jump" at the low point, in the opinion of this author, is nothing but a coincidence. After looking at the air temperature data that was also provided by the NDBC dataset, the air temperature goes from 10° C at noon on 02/01 to -4° C at noon on 02/02. This drastic change in air temperature is most likely the culprit behind the large "jump" in the water temperature interpolation. This "jump" is shown below in Figure 5.

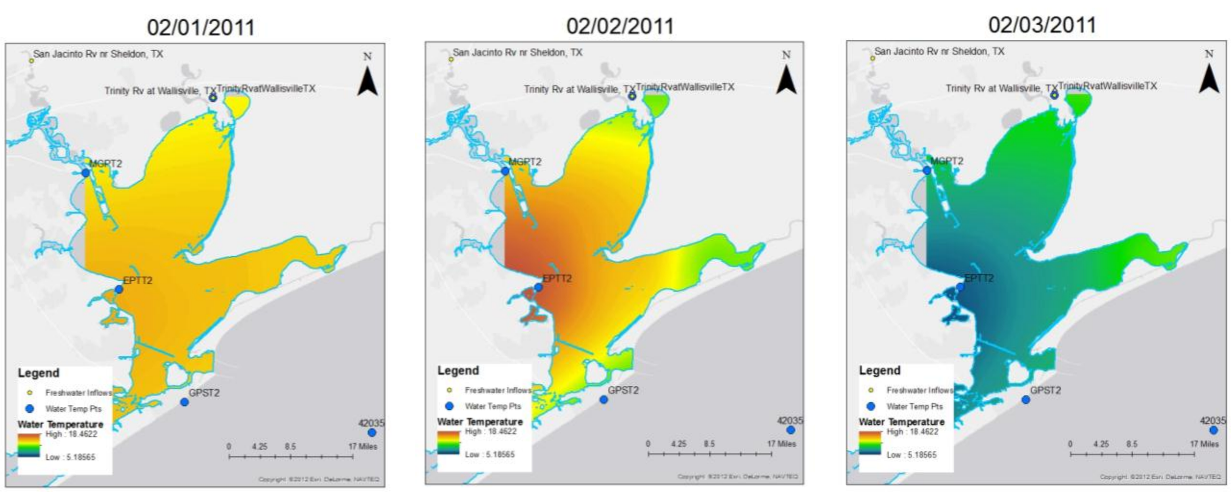

Figure 5: 3-day period showing "jump" in water temperature

Moving to the high freshwater inflow period, it becomes clear that there is no clear pattern between water temperature and freshwater inflow. For the first half of the period of interest, from 10/03 to 10/09, an interesting trend occurs. It appears as if the bay began the month of October with relatively large horizontal temperature gradients, which gradually dissipate over the next week. If one looks at the .GIF movie of the time period, they can see that the temperature over the bay becomes much more uniform as the first week progresses. This increased mixing, which can be seen in IFGURE, could be due to a wind event, and, in fact, the wind speed does appear to increase, if only slightly, from 10/03 to 10/07. However, more research into this correlation is needed for a definitive answer.

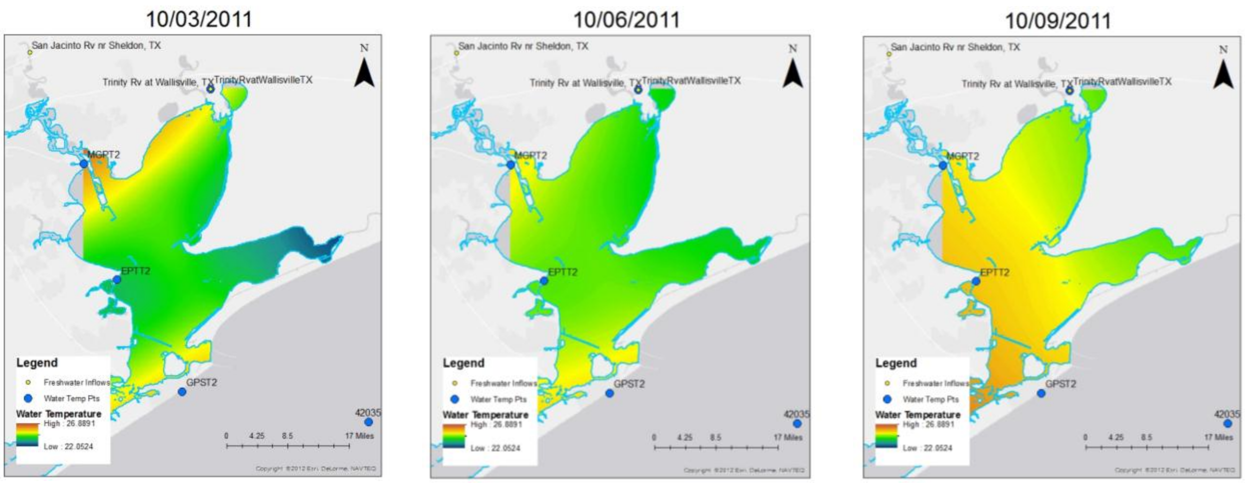

Figure 6: Mixing trend seen over the first week of the high freshwater inflow period

During the 4 days following the high-inflow event, the water temperature increases several degrees Celsius nearly everywhere in the bay. Again, this trend can be explained by the air temperature data. The air temperature on 10/10 at 5 pm local time was 24.0° C. By 9 pm on 10/13 the air temperature increased to 28.3° C, which, most likely caused the warming trend in the waters of Galveston Bay shown in FIGURE. Throughout this analysis, it became apparent that a much more informative comparison would have been air temperature to water temperature. The two are correlated well, but have a delay that seems to vary with time of day. This relationship would have been much more interesting, and perhaps should be the focus of future study. The few days following this warming trend show little relation to one another.

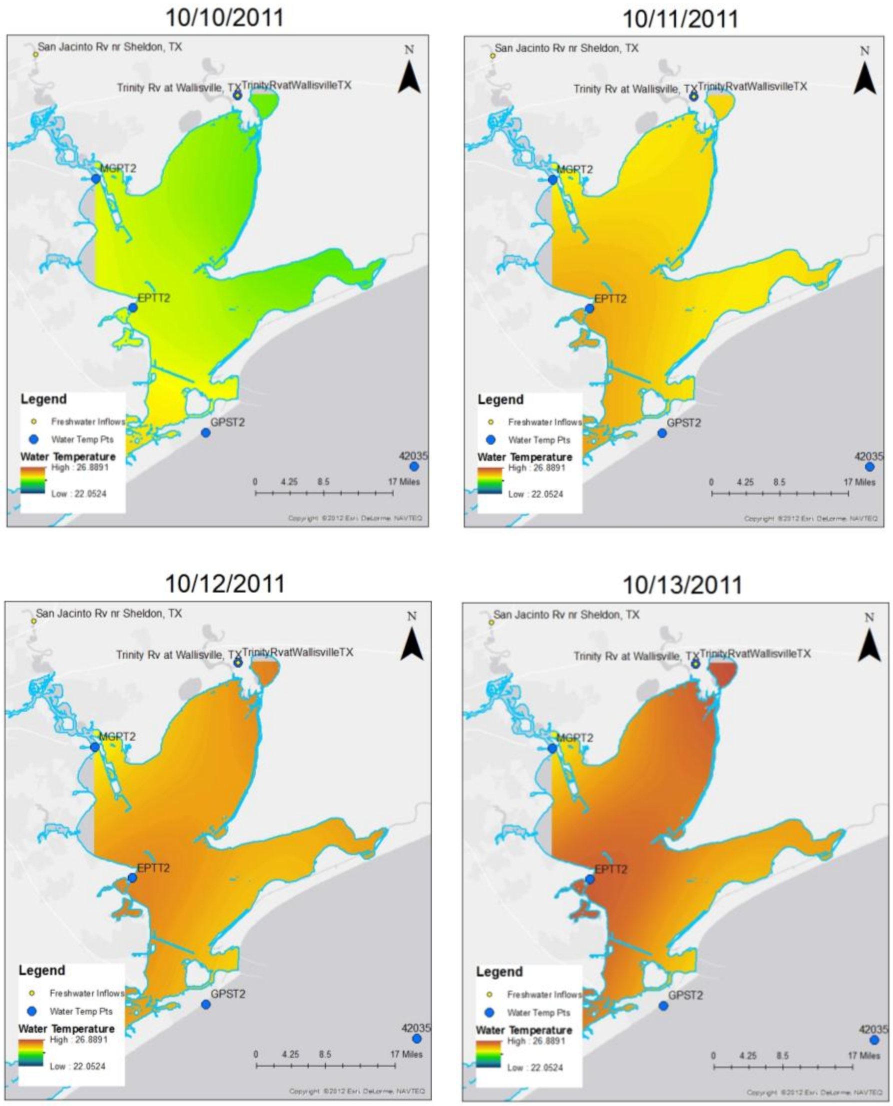

Figure 7: 4-day warming trend

Conclusion

After looking at time periods surrounding high and low freshwater inflow events, it has become clear that there is no correlation between water temperature and freshwater inflow. If there were a relationship, one would expect to see the changes begin near the mouth of the Trinity River and propagate southward into the rest of the bay, as the Trinity River is, by far, the largest contributor of freshwater inflow in Galveston Bay. If the effects of freshwater inflow in Galveston Bay, or any estuary for that matter, were of interest, salinity data for points within the bay would be very beneficial. The salinity of the water would, theoretically, correlate much better than temperature because freshwater is always going to decrease salinity. With water temperature, the relationship is more complex in that it depends on meteorological conditions as to whether the freshwater inflow is at a higher or lower temperature than the water already in the bay. The relatively straightforward relationship between salinity and freshwater inflow would yield a much better comparison between high and low freshwater inflows as well. The NDBC does include salinity data at some of its buoys. Unfortunately for this study, none of the NDBC buoys in Galveston Bay record salinity data.

Although, no clear relationship between freshwater inflow and water temperature was detected, several things were learned from this study. First, GIS is not only a great tool for visualizing spatial data, but for visualizing temporal variations as well. Second, water temperature in Galveston Bay seems to be well correlated to air temperature, and could be an interesting area of study in the future. Finally, any future studies focusing on freshwater inflows in an estuary should include salinity data, as the relationship between freshwater and salinity is relatively simple when compared to the relationship between freshwater inflow and water temperature.

Acknowledgements

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