**NASA DEVELOP National Program**



Mobile County Health Department

*Fall 2015*

Coastal Texas Water Resources II

Using NASA Earth Observations to Assess Laguna Madre Water Conditions through Land Cover Mapping and Thermal Analysis

 **Technical Report**

Final Draft – November 19, 2015

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# I. Abstract

This project was conducted to aid the National Park Service (NPS) in assessing the historical hydrology of the Laguna Madre located within Padre Island National Seashore. While the lagoon is now hypersaline, there is historical evidence indicating this was not always the case. It is hypothesized that the proliferation of the honey mesquite tree (*Prosopis glandulosa*) has contributed to the Laguna Madre’s increased salinity by tapping into groundwater, thereby reducing the amount of freshwater flow into the lagoon. The project team partnered with the NPS to analyze the suspected correlation between the occurrence of the mesquite trees and the salinity of the lagoon. NASA Earth observations were used in ArcGIS software and ERDAS IMAGINE to create time series maps and conduct data analyses. Landsat 5 Thematic Mapper (TM) data were used to create Land Use/Land Cover (LULC) maps to analyze the change in mesquite tree coverage as well as to calculate the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Infrared Index (NDII). Thermal maps of the lagoon were also created using Landsat 5 TM data to identify thermal anomalies in surface water temperature. These anomalies could indicate possible inflow locations of groundwater to the lagoon. *In situ* precipitation data were used to target months and years for analysis. Through these analyses, the NPS can improve future land management practices.

**Keywords**

Honey mesquite, normalized difference vegetation index, normalized difference infrared index, groundwater

# II. Introduction

***Background***

The Laguna Madre is one of only a few hypersaline estuaries in the world (Tunnel 2001). It is located within the Padre Island National Seashore on the Gulf Coast of Texas. As part of a National Park, the lagoon falls under federal land management. However, much of the nearby land is privately owned, complicating management of the Laguna Madre. As a result, the National Park Service (NPS) currently collects *in situ* data from limited locations to monitor different water properties of the Laguna Madre, such as temperature, pH, turbidity, and salinity (Meiman, Joe. Personal Communication. Fall 2015 Term).

Historical evidence suggests that while the lagoon is presently hypersaline, this was not always the case. It is hypothesized that the proliferation of honey mesquite (*Prosopis glandulosa*) trees in the surrounding area have resulted in decreased freshwater inflow to the lagoon. The mesquite trees have well-developed root systems capable of tapping into groundwater resources (Ansley 2015). However, the relationship between the salinity of the lagoon, honey mesquite trees, and groundwater resources, is not being systematically studied. As much of the area surrounding the lagoon is privately owned, remote sensing data is ideal to analyze the expansion of honey mesquite trees and their suspected effect on the Laguna Madre (Meiman, Joe. Personal Communication. Fall 2015 Term).

***Objectives***

The objective of this study was to use remote sensing technologies from NASA Earth observations to investigate the suspected positive correlation between the salinity of the Laguna Madre and the increase in honey mesquite trees. This was done in several ways. To start, honey mesquite tree expansion was analyzed from Landsat 5 Thematic Mapper (TM) data through a time series of Land Use/Land Cover (LULC) maps as well as through the calculation of vegetation indices including the Normalized Difference Infrared Index (NDII) and the Normalized Difference Vegetation Index (NDVI). The last portion of the project, in order to achieve the objective, was to identify potential areas of groundwater inflow to the lagoon. This was done by analyzing Landsat 5 TM’s thermal band to locate anomalies in the surface temperature of the lagoon, as images were collected during seasons when there should be a distinct difference between groundwater and surface water temperatures.

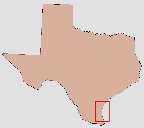
***National Application Areas Addressed***

By using NASA Earth observations to gather remotely sensed data to address water quality availability and forecasting concerns, this project addressed the Water Resources and Ecological Forecasting national application areas. Landsat was used to identify groundwater inflow into the lagoon through thermal analyses as well as examine the current and predicted changes in honey mesquite tree extent. In doing so, this project seeks to determine the relationship between these environmental factors and the health of the Laguna Madre.

***Study Area***

Figure 1. Study Area showing the Laguna Madre, Padre Island National Seashore.

Broadly speaking, the study area of this project included the Laguna Madre within the Padre Island National Seashore located on the Gulf coast of Texas as well as some of the surrounding lands to the west of the lagoon. The western boundary stretched past US Highway 77 while the eastern boundary extended into the Gulf of Mexico (Figure 1).

For thermal image analysis, this study area was focused on the Laguna Madre. For the LULC maps, the study area was focused on the landmass west of the Laguna Madre, extending eastward to Kingsville, TX and south to Edinburg, TX.

***Study Period***

The study period of the project spanned from 1986 to 2000. Land cover analyses and vegetation indices calculations were conducted incrementally. Late summer months, August to October, from these years were targeted due to the greater spectral difference between honey mesquite trees and surrounding vegetation, mostly grasslands. This is because the honey mesquite has taproots that can access water, keeping leaves green, whereas the surrounding vegetation cannot and would display browning from significant water stress.

Thermal data were downloaded for the mesquite trees’ dormant season, January – February, and the growing season, August – October. These months offered the greatest potential differences between the temperature of the lagoon and groundwater inflow. Years with similar climatic conditions were specifically targeted because it was hypothesized that there would be groundwater inflow during the dormant season when the trees are not taking up the water. Conversely, near the end of the growing season, there would be less groundwater inflow. Therefore, between the date during the dormant season and the growing season of the same year there would be a larger detectable difference in groundwater inflow to the lagoon.

***Project Partners***

This project partnered with the National Park Service (NPS) to address concerns over the rising salinity of the Laguna Madre. This is a concern to the NPS as the lagoon creates a diverse ecosystem that provides habitat to various flora and fauna, including threatened species such as the Kemp’s ridley sea turtle (*Lepidochelys kempii*) (Tunnel 2001). While the unique ecosystem of the lagoon is not in immediate danger from the increasing salinity, it remains unclear what effect various environmental factors are having. By analyzing mesquite tree expansion and thermal anomalies, the relationship between these factors will be better understood and will aid the NPS in future land management decisions concerning the Laguna Madre. Furthermore, several scripts and a methodology will be provided to the NPS in order to allow them to continuously monitor the health of the Laguna Madre using NASA Earth observations with no remote sensing experience necessary.

# III. Methodology

***Data acquisition***

***Precipitation data***

*In situ* data provided by the Kingsville, TX and Corpus Christi, TX weather stations for the same time period. Using these datasets allowed for dates with similar climatic conditions to be targeted for thermal analysis.

***Thermal Imagery***

Landsat 5 TM data from path 26 row 41 and 42 were downloaded from the USGS LandsatLookviewer and the USGS EarthExplorer for the thermal analysis. As the study period was between 1986 and 2000, only Landsat 5 TM was required. Months from the dormant and growing season of the same year with similar climatic conditions were downloaded. The years were paired as follows: November 18, 1986 and January 5, 1987, July 29, 1992 and February 6, 1993, August 1, 1993 and January 8, 1994, October 12, 1996 and February 17, 1997, and September 29, 1997 and January 19, 1998.

***Land classification***

Path 26 row 41 and 42 data provided by the Landsat 5 TM satellite were acquired from the USGS LandsatLookviewer and the USGS EarthExplorer website. A time series of LULC maps were generated using Landsat 5 TM. Landsat 5 TM data were collected for two years: July 29, 1986 and September 5, 2000. These dates were then used to conduct land cover analyses in order to examine the change in extent of mesquite tree coverage. Data from Landsat 5 TM for the same dates were used to calculate the NDVI and NDII vegetation indices.

***Script Development***

***Python Function for historical thermal data***

Several scripts were developed in order to increase efficiency of data preprocessing. This helps the team, and it will also be given to the project partner to allow them to conduct separate analyses with very little background knowledge for images that we did not analyze. These scripts will be for Landsat 5 TM. All the project partner will have to do is download the satellite image with associated metadata, input a few key parameters and run the scripts. Digital numbers will be converted to TOA radiance, which will then be converted to Celsius temperatures and then output into a new folder. At this point, the images can be uploaded into a GIS or image processing software to be easily analyzed.

***Data Processing***

***Thermal Imagery***

The raw Landsat 5 TM band 6 data were converted to Top of Atmosphere (TOA) radiance using a python script. The images were mosaicked together and clipped to the study area. Then each thermal image was converted to an 8-bit unsigned file to be uploaded into ERDAS IMAGINE. An unsupervised classification was run, followed by a supervised classification in order to create a land mask. The land mask was then applied to the thermal image in ArcMap using the conditional tool. Then the lagoon was clipped and extracted using a dnppy script and a shapefile of the lagoon. Lastly, the thermal data were converted to Celsius using a Python script.

***Land Classification***

Landsat 5 TM bands 2, 3, and 4 were converted to TOA reflectance. A cloud mask was then applied to all of the bands using a dnppy script. The bands were then mosaicked together and clipped to the extent of the study area. Then the bands were stacked in ArcMap (4, 3, 2) for color infrared visualization. Then the data were converted to 8-bit unsigned files to be uploaded into ERDAS IMAGINE for the land cover classification. A supervised classification was run to create a water mask for each land cover scene.

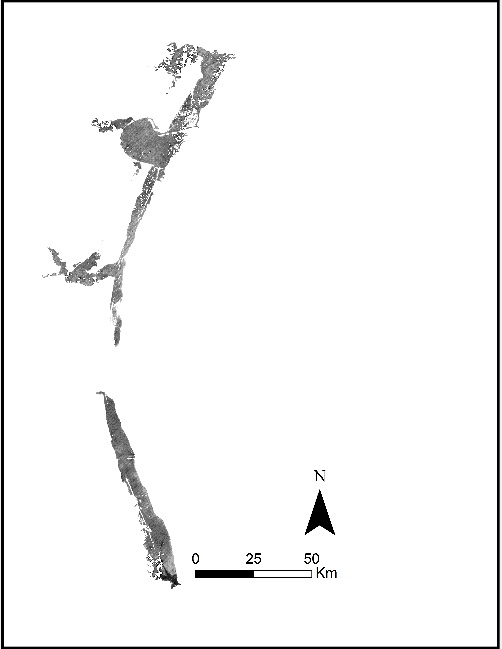
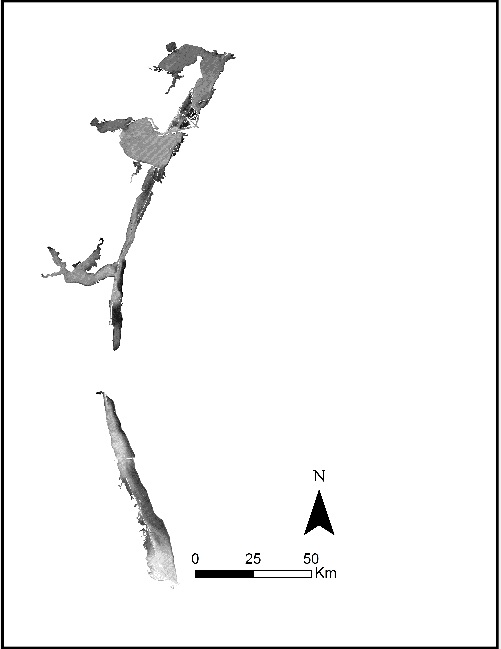
***Vegetation Indices***

Landsat 5 TM bands 3 and 4 were used to calculate the NDVI and bands 4 and 7 were used to calculate the NDII. All bands were converted to TOA reflectance. A cloud mask was applied using a dnppy script. Then the bands were mosaicked and clipped to the study area. The water mask created for the land classification date correlating to the NDVI and NDII date were applied to both indices’ data.

***Data Analysis***

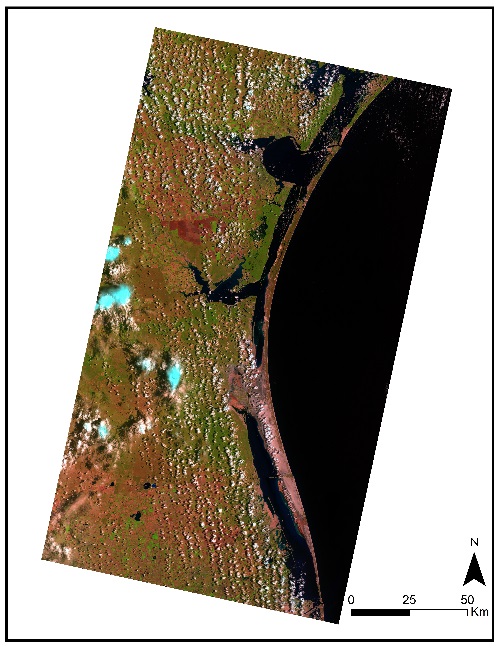
***Thermal Imagery***

First a visual analysis of the lagoon was done. During the dormant season it was hypothesized there would be a hotspot in the lagoon caused by fresh groundwater inflow. In contrast, during the growing season it was hypothesized the inflow of groundwater would cause a cool spot to appear or, that because the mesquite trees took up groundwater during the growing season, there would be no anomaly where previously, in the dormant season, there had been one. Thermal imagery analysis continued by first resampling the pixel size from 30 m by 30 m to 90 m by 90 m in order to convert the thermal raster to a point layer. Then, the “Hotspot Analysis” tool was run in ArcGIS software to attempt to identify thermal anomalies. A third method to analyze thermal data was done through a change detection which was done by using the “Spatial Modeler” in ERDAS IMAGINE (Figure 2). This was done for all ten dates selected for thermal analysis (Appendix 1, Figure 6). The background data set to a value of 101 and was removed by a conditional statement that only kept data points ranging in value from 0 to 100. The statistics provided by ERDAS software exclude the background values. These values were chosen based knowledge of the climate in Texas. It was assumed that the temperature of the water would not go below 0°C or above 100°C. The percent change in the surface temperature of the lagoon was calculated by taking ambient temperature, or global mean temperature, and subtracting it from the raster data for each date of thermal data. Then the result was divided by the global mean temperature and multiplied by 100 to calculate the percent change.  This equation normalized the data using the global mean temperature. By using the change detection method to analyze the thermal data the percent change, differences between individual pixels and the global mean temperature could be seen for the entire length of the lagoon.

**February 1993**

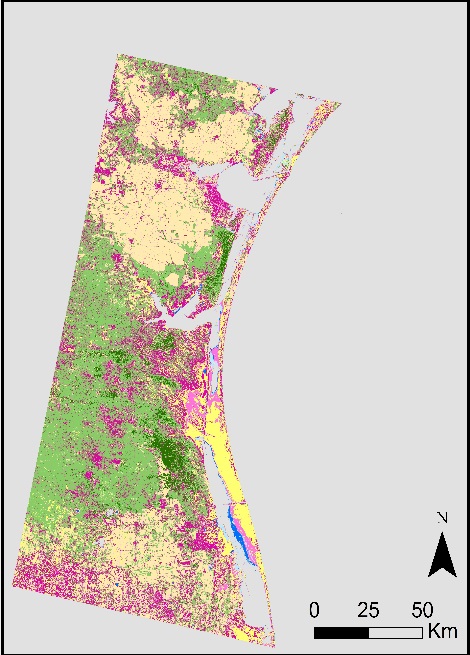
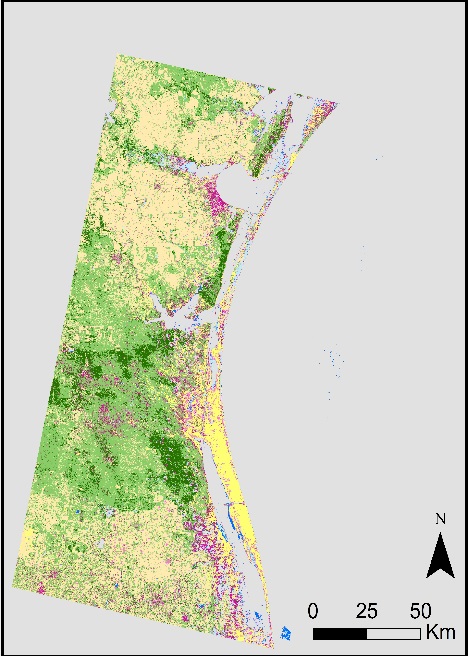
**July 1992**



**Figure 2.** Thermal images for July 1992 (left) and February 1992 (tight), and the false color image of the study area using Landsat 5 bands 5, 4, 3 stacked in that order (bottom).

***Land Classification***

A land cover classification was done for two dates: July 29, 1986 and September 5, 2000 using the bands stacked for infrared visualization. Training regions were created in ERDAS IMAGINE for each of the land cover categories. Our study area was classified into eight categories: urban, suburban, cropland/bare soil, grassland, sand, water, wetland, and mesquite trees (Figure 3). Once these regions were created and added to a signature file in ERDAS IMAGINE, a supervised classification was then run. Once the eight land cover classes were created, an accuracy assessment was done for each land classification. Twenty-five points per class were used to do the accuracy assessment. These points were randomly and equally distributed between classes.

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**July 1986**

**September 2000**

Figure 2. LULC images for July 1986 (left) and September 2000 (right)

***Vegetation Indices***Two vegetation indices, the NDVI and the NDII were calculated to supplement the land cover classifications. The NDVI was calculated for each date corresponding to a land cover classification. The NDVI is a measure of photosynthetic activity in vegetation. This vegetation index is a ratio utilizing near infrared band and the red band (Appendix III, Table 3)

(1)

where NIR is the near infrared reflectance and Red is the red reflectance. The areas of photosynthetic activity shown by the NDVI were compared with the land cover classifications. In addition to the NDVI, the NDII was also calculated for dates corresponding to the two land cover classifications. The NDII was also calculated for each date corresponding to a land cover classification. Similar to the NDVI, the NDII is also a ratio. However, the NDII utilizes the near infrared band and the short wave infrared band (Appendix III, Table 3)

(2)

where NIR is the near infrared reflectance and SWIR is the short wave infrared reflectance (Hoshino, et al. 2011). The foliar water content shown by the NDII indicates the water stress level of vegetation. The areas which were less stressed as shown by the NDII maps were compared to the locations of the mesquite trees shown by the LULC maps since it is hypothesized mesquite trees can tap into groundwater resources.

# IV. Results & Discussion

***Analysis of Results***

***Thermal Imagery***

The initial visual analysis of the Laguna Madre yielded no results. The second method, converting the thermal raster to a point layer, again identified no thermal anomalies in the surface temperature of the lagoon. However, by using the change detection areas of interest were identified with larger change being detected. Specifically, areas in the lower Laguna Madre near the southern border of Texas showed temperatures which were cooler than the global mean temperature during the growing season month (Figure 4). This same area appeared to be warmer during the dormant season. An anomaly was also detected in both the growing and dormant season in the Nueces Bay area. However it is suspected that this anomaly was caused by a nearby industrial plant since this anomaly stayed consistent across climatological events such as fluctuations in precipitation amounts.

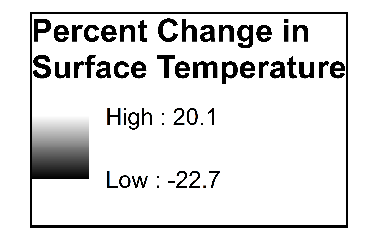
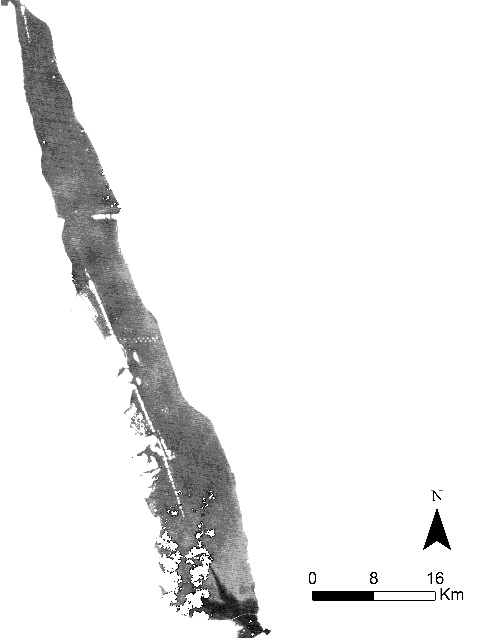


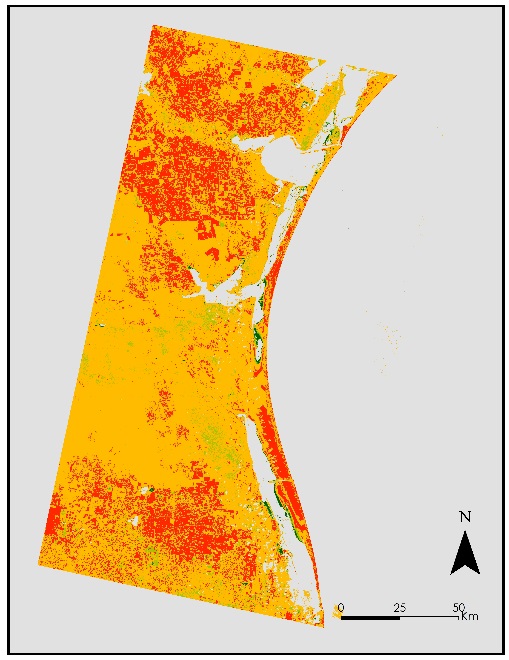
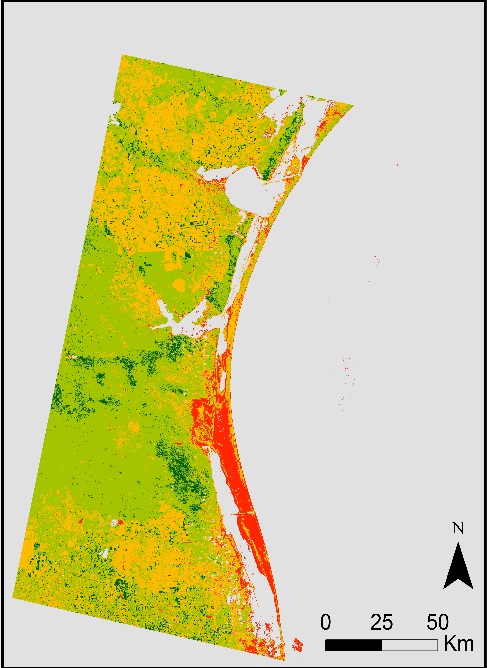
Figure 4. Just the southern portion of the Laguna Madre is shown. The percent change in surface temperature from the global mean of the lagoon is shown in gray scale (left) from July 1992. The false color image of the study area is shown right.

***Land Classification***

An accuracy report was generated giving overall statistics as well as statistics for individual classes. The overall accuracy for July 29, 1986 was 63.1% and the overall Kappa statistic was 0.59. The producer’s accuracy of the mesquite tree class, which was main class of interest, was 80.8% and the user’s accuracy was 84.0%. The Kappa statistic for this class was 0.82 which fell within the “almost perfect agreement” category (Table 1). The overall accuracy for September 5, 2000 was 58.9% with an overall Kappa statistic of 0.53. The producer’s accuracy of the mesquite tree class was 48.7% and the user’s accuracy for this class was 86.4%. The Kappa statistic for the mesquite tree class was 0.84 which also fell within the “almost perfect agreement” category according to Landis and Koch-Kappa’s Benchmark Scale from 1977 (Appendix II, Table 2). The mesquite class accuracy was higher than the overall accuracy and had better agreement according to the Kappa statistic.

Table 1. Land Use/Land Cover – Accuracy Totals – 25 samples per class

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Overall Classification Accuracy** | **Overall Kappa Statistics** | **Mesquite Tree Class – Producer’s Accuracy** | **Mesquite Tree Class – User’s Accuracy** | **Mesquite Tree Class – Kappa Statistics** |
| Jul 29, 1986 | 63.1 % | 0.59 | 80.8% | 84.0% | 0.82 |
| Sep 5, 2000 | 58.9% | 0.53 | 48.7% | 86.4% | 0.84 |

The areas of high photosynthetic activity identified (NDVI) and the areas of low water stress in vegetation (NDII) approximately corresponded to areas identified as mesquite trees in the land classifications (Figure 5). Both vegetation indices show similar results for September 2000(Appendix III, Figures 7 and 8).

**July 1986**

**July 1986**

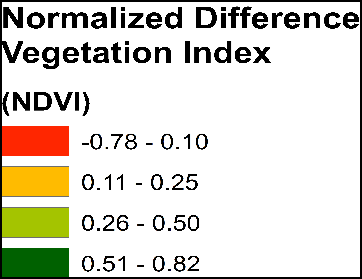
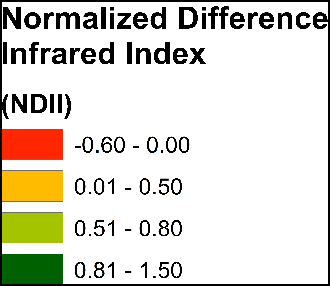
 

Figure 5. The NDVI from July 1986 (left) shows areas of higher photosynthetic activity in green and the NDII form July 1986 (right) shows areas of lower water stress in vegetation in green.

***Errors and Uncertainty***

There were several errors and uncertainties related to the project. First, the spatial resolution of the data may have limited the accuracy of the results. Especially resampling the thermal data to a coarser resolution may have inhibited the ability to detect thermal anomalies. The resolution of the data may have also caused error in the land cover classification. Many pixels were mixed since each covered such a large area. This meant pixels contained more than one class type and these pixels were classified by whichever land class was the majority in the pixel. This meant the area of the majority class was exaggerated and the area of another class was underestimated. Additional error occurred in the land cover classification due to class confusion as a result of similar spectral responses between land cover classes such as the urban and sand classes. Cloud cover over the study area resulted in error in the land cover and thermal analyses. The physical properties of the lagoon also led to error in analyses. The lagoon is a very shallow body of water making it susceptible to climatic conditions such as precipitation, cloud cover, and air temperature. These properties may have affected the quality of the thermal data.

***Future Work***

There are several directions which the project could continue. Since the lagoon is shallow, it may be beneficial to study the effects of precipitation amounts and evapotranspiration rates on the water conditions of the lagoon. Additionally, studies of the hydraulic gradient and direction of groundwater flow could provide additional insight into the factors driving changes in the Laguna Madre’s salinity. Precipitation could also impact the hydraulic gradient, and therefore may be worth studying for this reason as well. Lastly, future studies could focus on the effects of varying climatic conditions and effects these have on data quality.

# V. Conclusions

During the study period there was an observed decrease in the areas of mesquite tree coverage from 1,443 km2 (1986) to 641 km2 (2000). This trend contrasted with the original hypothesis. However, the areas identified as mesquite tree coverage did approximately align with the areas of higher photosynthetic activity identified in the NDVI calculation. This may indicate that the mesquite trees are more photosynthetically active. The areas of mesquite tree coverage also corresponded with areas of high water content meaning the vegetation in these areas is less stressed. This result may show that the mesquite trees are able to access water while other nearby vegetation cannot. No anomalies could be absolutely identified during the thermal analysis of the lagoon. However, the change detection provided a method to examine differences between the global mean temperature and temperature values along the length of the lagoon. Potential anomalies were identified but the source of these anomalies was not confirmed. Analysis will continue and provide groundwork for future studies.

# VI. Acknowledgments

The team would like to thank the following people for their help in the completion of this project: mentor Bernard Eichold, M.D., Dr. PH (Mobile County Health Department), the team’s Science Advisors Joe Spruce (NASA Stennis Space Center), the DEVELOP National Program’s National Science Advisor Dr. Kenton Ross (NASA Langley Research Center), as well as the team’s project partner and end-users, Joe Meiman (National Park Service) and Dr. Dorina Murgulet (University of Texas A&M, Corpus Christi, TX).

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Aeronautics and Space Administration.

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# VII. References

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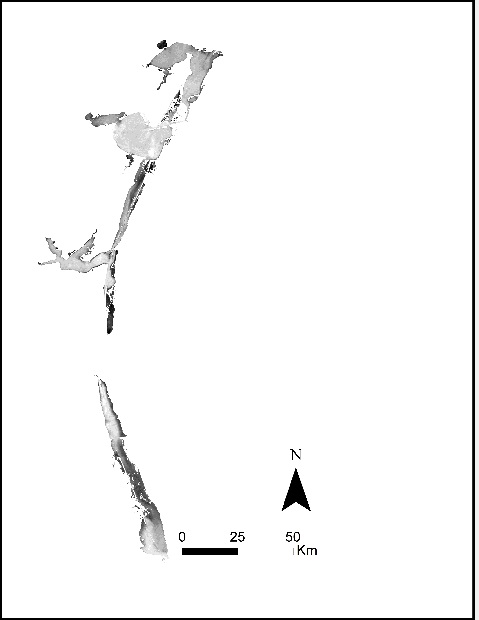
United States Geological Survey. 2014. LandsatLook Viewer. http://landsatlook.usgs.gov/ (November 17, 2015).

# VIII. Content Innovation

1. AudioSlides
2. Glossary
3. Featured Multimedia for this Article (VPS)

# IX. Appendices

**Appendix I. Thermal Imagery**

**January 1994**

**August 1993**

**January 1987**

**November 1986**

**January 1998**

**September 1997**

**February 1997**

**October 1996**

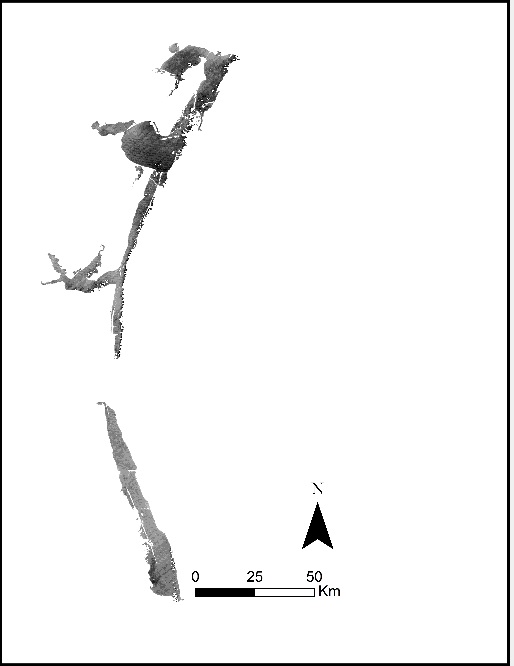
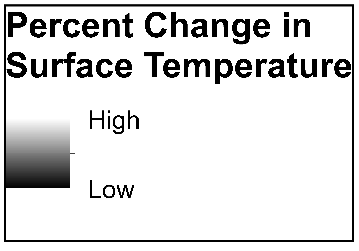
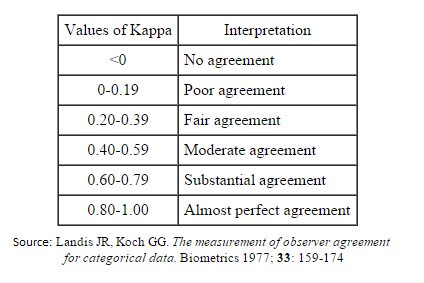
  

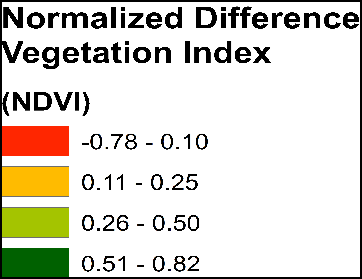
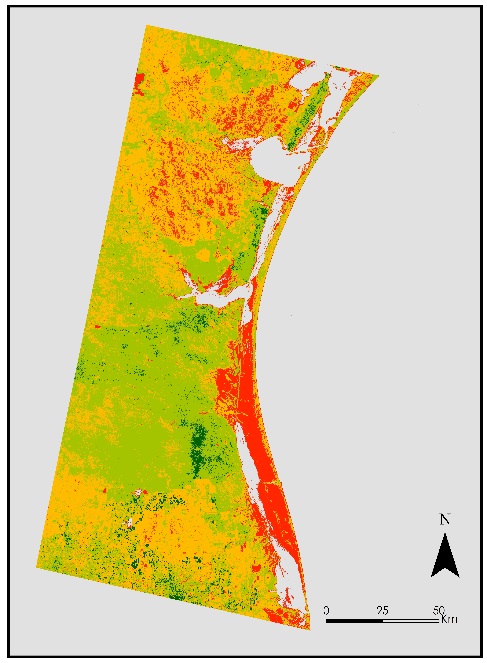
Figure 6. Thermal images of the Laguna Madre showing the percent change in surface temperature from the global mean temperature of each date.

**Appendix II. Land Use/Land Cover**

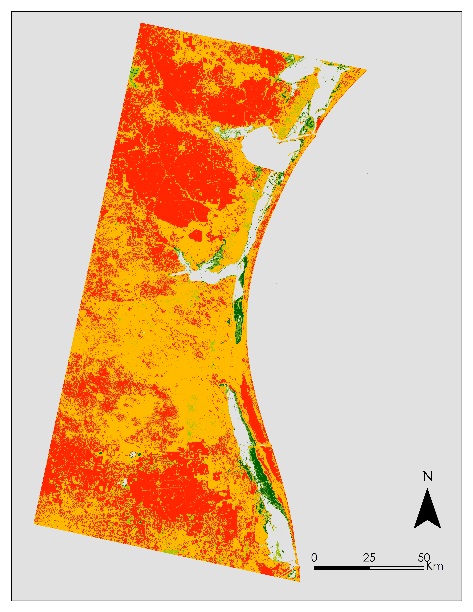
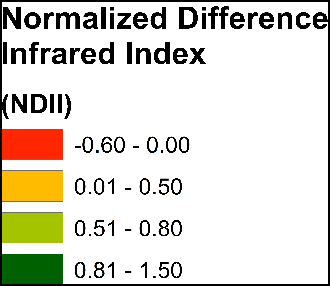
Table 2. Kappa Statistic Thresholds for Observer Agreement



**Appendix III. NDVI and NDII Images and Bands Used**

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**Figure 7.** NDVI images for September 2000

**Figure 8**. NDII images for September 2000

Table 3. The NIR, Red, and SWIR bands and their wavelengths used to calculate the NDVI and NDII for the Landsat 5 satellite.

|  |  |
| --- | --- |
| **Landsat 5 TM Band** | **Wavelength** |
| Band 3 - Red | 0.63 µm – 0.69 µm |
| Band 4 – Near Infrared (NIR) | 0.77 µm – 0.90 µm |
| Band 7 – Short Wave Infrared (SWIR) | 2.08 µm – 2.35 µm |