PERFORMANCE REPORT – FINAL

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TEXAS

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MONITORING AND PREDICTIVE MODELING OF WATER TEMPERATURES IN THE LAGUNA MADRE

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ABSTRACT

The Laguna Madre is the longest hypersaline lagoon in the United States and extends southward for over 200 miles from Corpus Christi, Texas to the United States-Mexican border. The passage of cold fronts can dramatically lower air temperatures by more than 10°C in less than 24 hours leading to considerable decreases in water temperature. Records from the past 20 years reveal that some of these cold water events resulted in massive fish kills. To mitigate the impact of such events, local agencies and stakeholders are considering interrupting activities such as fishing and boating. The main goals of the study were to measure water temperature profiles in the Upper Laguna Madre and to design, test and implement a water temperature predictive model with a particular emphasis on cold water events.

Water temperature profiling stations were installed in the Upper Laguna Madre in the 'land cut' area. Water temperatures were monitored hourly at about 3', 6', 9' and 12' depths. Several cold water events were recorded including a January 2007 event with water temperatures decreasing from 22.5°C down to 4.6°C in 60 hours. Throughout the study period the water temperatures were found to be mostly homogenous, i.e. temperatures within a 0.5°C range throughout the water column. A small moderating effect at the bottom of the channel, i.e. for the 12' sensor, was observed during sharp temperature rises. Bottom temperatures during these events stayed cooler by 1°C to 2°C up to 5°C but the temperature gradients always rapidly disappeared at the most within 8 hours. This moderating effect at the bottom of the Laguna Madre was however not observed during the sharp temperature decreases associated with frontal passages. The results of this study indicate a homogeneous water column temperature during cold water events. This likely excludes the hypothesis that marine life may seek warmer temperatures at the bottom of the Intracoastal Waterway during such events. No significant water temperature differences were observed between locations in the Upper Laguna Madre with the exceptions of stations close to ship channels or deeper water where the moderating effect of the Gulf of Mexico water could be observed.

The predictive water temperature model was developed based on Artificial Neural Networks. Model performance was computed for several years with yearly average absolute errors ranging from about 0.3°C for 3 hour predictions to about 0.7°C for 12 hour, 1.0°C for 24 hour and 1.7°C for 24 hour predictions (using a perfect prog approach for air temperature predictions). Cold water performance was analyzed for four events between 2003 and 2007 during which cold water temperature reached 8°C or below. The performance was computed using past WRF-NAM operational predictions. The mean average absolute error was lower than 1°C for all predictions increasing from 0.1°C for 3 hour predictions to 0.9°C for the longer prediction times. The performance of the model for cold water event was also evaluated based on its accuracy to detect events. The likelyhood that an event indeed takes place once predicted varied from 90% for 3 hour predictions to 85%, 83% and 64% for 12, 24 and 40 hour predictions. The operational model is implemented as part of the DNR/TCOON website and is available at following url: http://lighthouse.tamucc.edu/Forecasts/WaterTemperatureForecasts.

PERFORMANCE REPORT

State: Texas **Grant Number:** T-9

Grant Title: Monitoring and Predictive Modeling of Water Temperatures in the Laguna Madre

Program: Coastal Fisheries

Project No. and Title: Contract # 158833 - Monitoring and Predictive Modeling of Water Temperatures in the Laguna Madre

Report Period: January 24, 2006 through August 31, 2007

I. Objectives:

The objective of the study were to (1) install water temperature profiling stations in and around the 'land cut' area of the Upper Laguna Madre, Texas, (2) test, monitor, maintain, and analyze the data from the water temperature profiling stations, (3) develop a water temperature predictive model particularly for the prediction of cold water events, i.e. events resulting in water temperatures at or below 45°F, and (4) implement the model on the world wide web to make its predictions accessible to decision makers.

II. Background:

The Laguna Madre is the longest hypersaline lagoon in the United States and extends southward for over 200 miles from Corpus Christi, Texas to the United States-Mexican border. The Laguna Madre is home to fragile young finfish, shrimp, and shellfish as well as redfish, spotted sea trout, a host of birds, and endangered sea turtles (Britton and Morton, 1989). The passage of cold fronts can dramatically lower air temperatures by more than 10°C in less than 24 hours which leads to a considerable decrease in water temperature. Records from the past 20 years reveal that some of these cold water events resulted in massive fish kills. In 1997, more than 94,000 fish died in the Lower Laguna Madre and over 48,000 fish died in the Upper Laguna Madre (TPWD, 1997). To mitigate the impact of these cold events, local agencies and stakeholders are considering interrupting activities such as fishing and boating during these events. To help manage such interruptions accurate predictions of occurrences and length of cold water events would be invaluable. An accurate model would result in significant economical benefits as the water bodies could be closed for an optimum time span limiting short term economic losses due to the interruption of recreational and commercial activities while helping mitigate the impact of the cold water events. The study seeks to better understand the dynamic and forcings of the water column temperatures in the Upper Laguna Madre and to develop a predictive model that could help implement preventive actions ahead and during the cold water events.

III. Procedures:

The general project methodology is illustrated in Figure 1. The project is initially divided into two tracks, a monitoring and a modeling track, and concludes with the development and implementation of a web accessible predictive model for the monitoring stations. The two measuring stations were installed at existing platforms to leverage existing infrastructure of the Texas A&M University-Corpus Christi (TAMUCC) Division of Nearshore Research (DNR) and the Texas Coastal Ocean Observation Network (TCOON). The stations locations are illustrated in Figure 2 with the abbreviations TPWD (Texas Parks & Wildlife Department) LC for the Land Cut station and RI for the Rincon station. The Rincon station was installed on the same platform as the Texas Coastal and Ocean Observation Network (TCOON) Rincon station platform (26° 48.090' N, 97° 28.236' W). The concurrent installation provided for a sturdy platform, and the concurrent measurement of other related variables such as wind, air temperature, barometric pressure and water level at the same location. The Land Cut station was installed using the platform of the former El Toro station (26° 55.883' N, 97° 27.388' W). In this later case no other instrumentation is located on the station besides the project sensors. Measurements started respectively on February 27, 2006 and December 13, 2005 for the Rincon and Land Cut stations. Two other TCOON stations are located near the project station, the Baffin Bay station northward and the Port Mansfield station southward of the project stations. The Bird Island station used for the initial model development is located further northward from the Baffin station on the northern end of the Laguna Madre. Thermistor strings composed of 4 YSI® 44032 (YSI, 2007)] thermistors attached to a steel cable were assembled for the project. The YSI thermistors were purchased in bulk and assembled each with 18-2 gauge copper wires for the electrical connection, and potted into an ECOBOND epoxy matrix (Emerson & Cuming ECCOBOND 45 Black plus ECCOBOND Catalyst 15 Black epoxy). The in-house manufacturing of the thermistor strings gives the flexibility to have strings of any desired length and spacing. Each thermistor is tested for accuracy prior to field deployment. The test is carried out by submerging the sensors in an ice bath and comparing their readings to a laboratory thermometer. The voltage response of each thermistor is monitored as the ice melts and as the bath reaches room temperature. The temperatures are then computed from the voltage outputs. Once calibrated the thermistors and the rest of the equipment is transported to the station location. The deployment geometry is illustrated in figure 3. The steel cable is deployed from the platform and along the slope of the dredged Intracoastal Waterway. The platform is in typically 2-3’ of water while the nominal dredged depth of the Intracoastal Waterway is 14-15’. The thermistors are attached to the cable at locations selected such that their respective depths are approximately 3’, 6’, 9’ and 12’. The sensor locations, i.e. locations along the steel cable, are established using a Garmin GPS492 depth sounder/GPS unit. The thermistors are zip-tied to the steel cable. The tip of each thermistor is left free to float 8”-10” above the Laguna floor and its muddy bottom with a fishing cork attached to the sensor for flotation. All 4 thermistors are connected to a Sutron Satlink II dataloger (SL2- G312-1) (Sutron, 2007) purchased from Sutron Corperation www.sutron.com. A 30KOhm Resistor is placed in series with each thermistor circuit per Sutron Satlink II instructions which completes the sensor deployment. Transmission of the measurements takes place through satellite

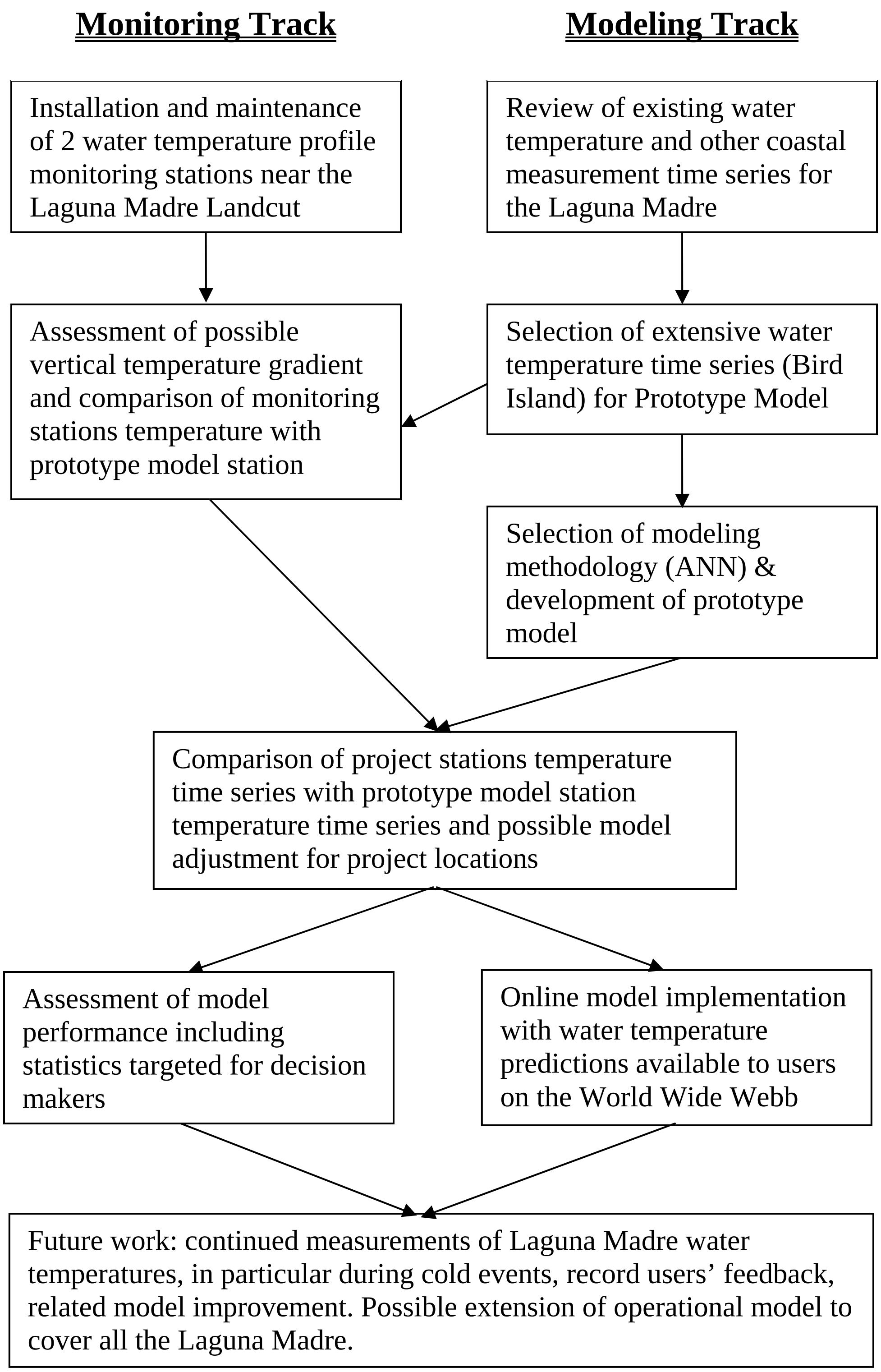

Figure 1. General study plan for monitoring, study and design and implementation of predictive model of water temperatures in the Laguna Madre.

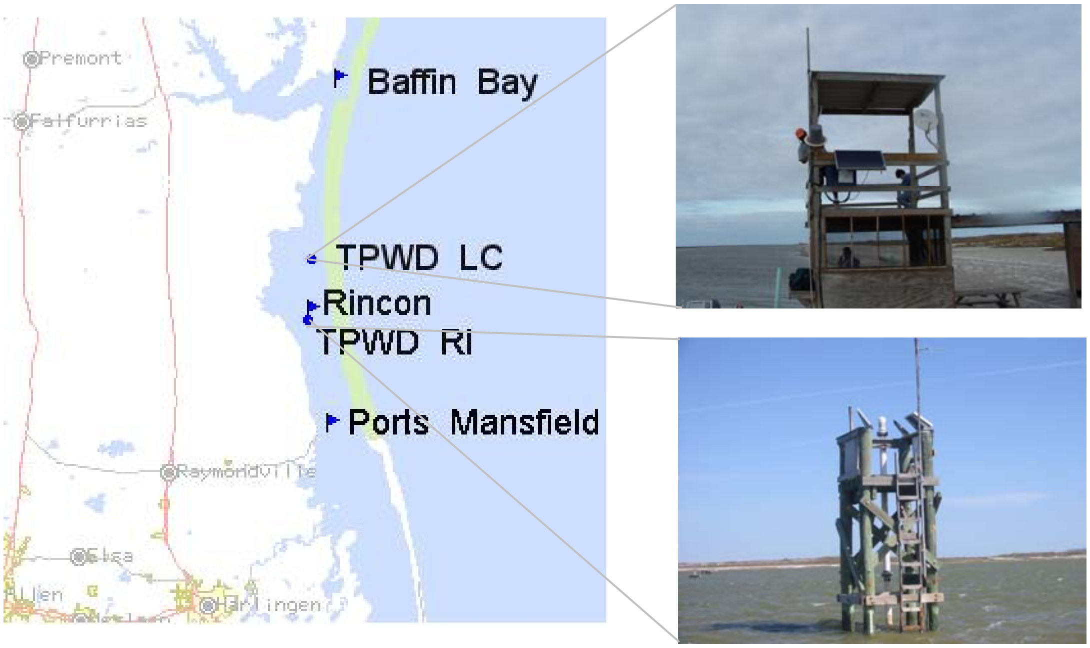

Figure 2. Locations and pictures of the project stations: the Land Cut Station (TPWD LC) & the Rincon Station (TPWD RI) as well as the surrounding TCOON stations.

Table 1. Detailed information for the two project stations and the collected time series

Station Name:	Texas Parks & WIldlife Department, Rincon Station	Texas Parks & WIldlife Department, Land Cut Station
DNR ID:	140	141
Abbreviation:	TPWDRI	TPWDLC
Location:	26° 48.090' N, 97° 28.236' W	26° 55.883' N, 97° 27.388' W
	26.8015000 / -97.4706000	26.9313900 / -97.4564700
url:	http://lighthouse.tamucc.edu/overview/140	http://lighthouse.tamucc.edu/overview/141
Information collected:	water temperatures at 4 depth within the water column	water temperatures at 4 depth within the water column
Data collection Start:	February 27, 2006	December 13, 2005
Communication:	Satellite transmission, measurements available on the web typically within 1 hr.	Satellite transmission, measurements available on the web typically within 1 hr.
Check / Maintenance:	July 24, 2007: Station inspection – No replacement	July 24, 2007: Replacement of thermistor string
Other information:		Added correction record for wtp1, wtp3, wtp4 to remove data from 2007178+1130 to 2007198+0000 as per John Adams.

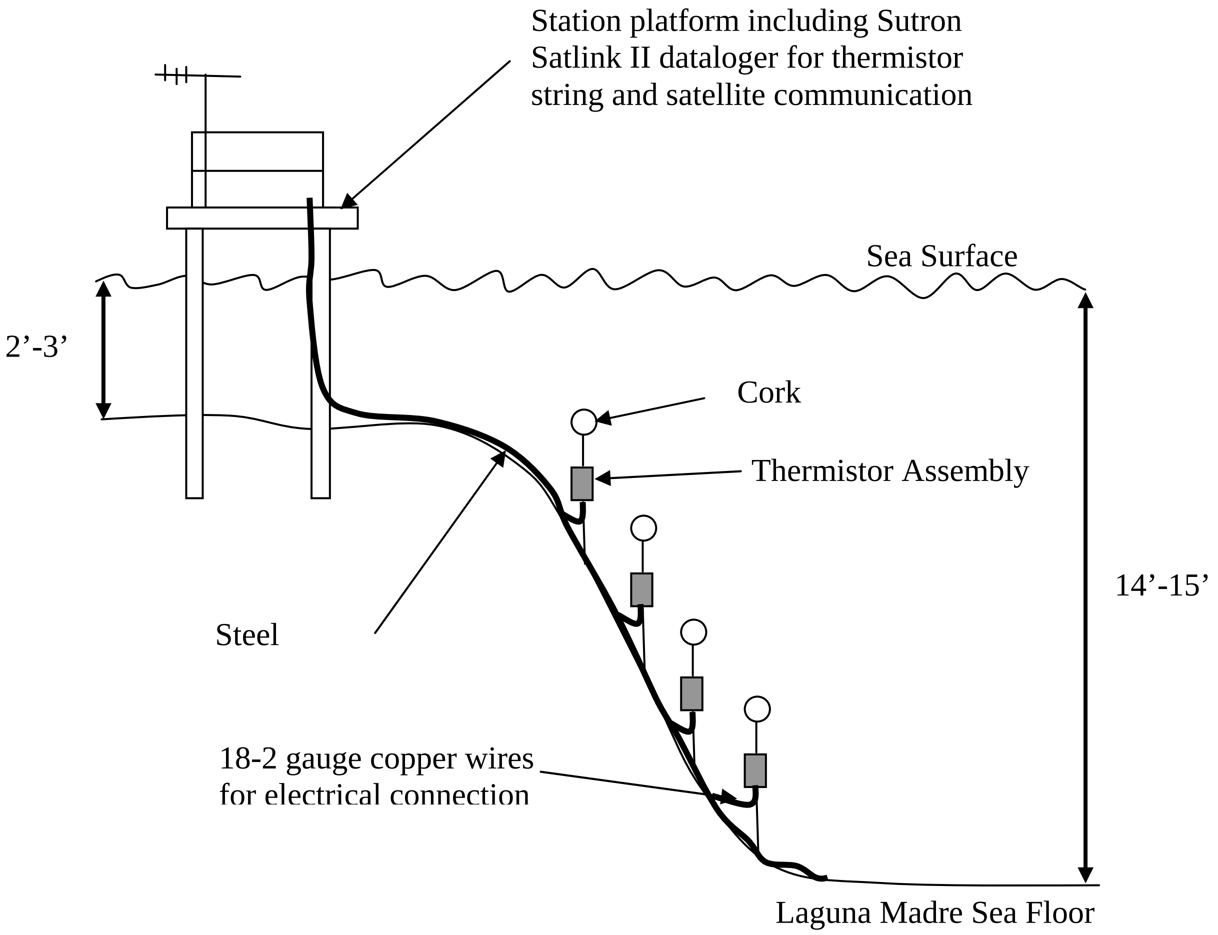

Figure 3. Schematic of the sensor deployment for both project stations.

communication typically on an hourly basis. The main information regarding location, installation, instrumentation and maintenance of the stations is presented in abbreviated format in Table 1. The temperature time series are available on the World Wide Web through the DNR website (http://lighthouse.tamucc.edu).

The water temperature model development was based on the extensive history of water temperatures and other related time series of the TCOON South Bird Island Station. The station is located south of Corpus Christi Bay in the Upper Laguna Madre, North of the two project locations. The recently installed project stations did not have sufficient data to build a reliable model, especially for the infrequent cold water temperature events of particular interest to this study. Data sets from other stations were considered for the model to account for the possible influence of nearby water bodies, i.e. Corpus Christi Bay and the Gulf of Mexico. Eleven yearly records (1995 to 2005) of air and water temperature were considered. For the training and optimization of the models and the calculation of correlation coefficients the yearly data sets of 1995, 1996, 2000, and 2001 were selected. Corresponding yearly data sets from the nearby Bob Hall Pier and Ingleside Stations were included as well to account for the possible influence of the nearby larger water bodies. These later data sets consist of air temperature, water temperature, wind speed and wind direction, as well as measured and harmonically predicted water levels.

The modeling technique selected to predict water temperatures was Artificial Neural Networks. The technique was selected because of the non-linear nature of some of the relationships between forcings and water temperatures and because of the implementation capabilities of DNR. A neural net model was also selected for this work over other techniques because of its robustness to noisy data, and generic modeling capability (Hagan, et al., 1996, Rumelhart and Chauvin, 1995). The ANN model was compared with a multi linear regression model to estimate the advantage of having selected the technique. The overall model design strategy is illustrated in Figure 4. The ANN model design for input selection followed the stepwise method (Wilks, 2006), i.e. progressively adding and comparing possible inputs to the model to determine the optimal number of previous measurements to include in the model. The order or consideration of the various input was based on the correlation strength with future water temperatures at the mdoel station. Rather than experimenting with the number of neurons and the number of hidden layers, our initial model followed the approach taken by Tissot, et al. This study found that simple [1,1] neural networks performed best for predictive modeling of water levels at the same location (Tissot et al., 2003). More complex neural network structures were tested once the [1,1] model was optimized. For the initial model a tansig function was used for the hidden layer neuron and a purelin function for the output layer neuron

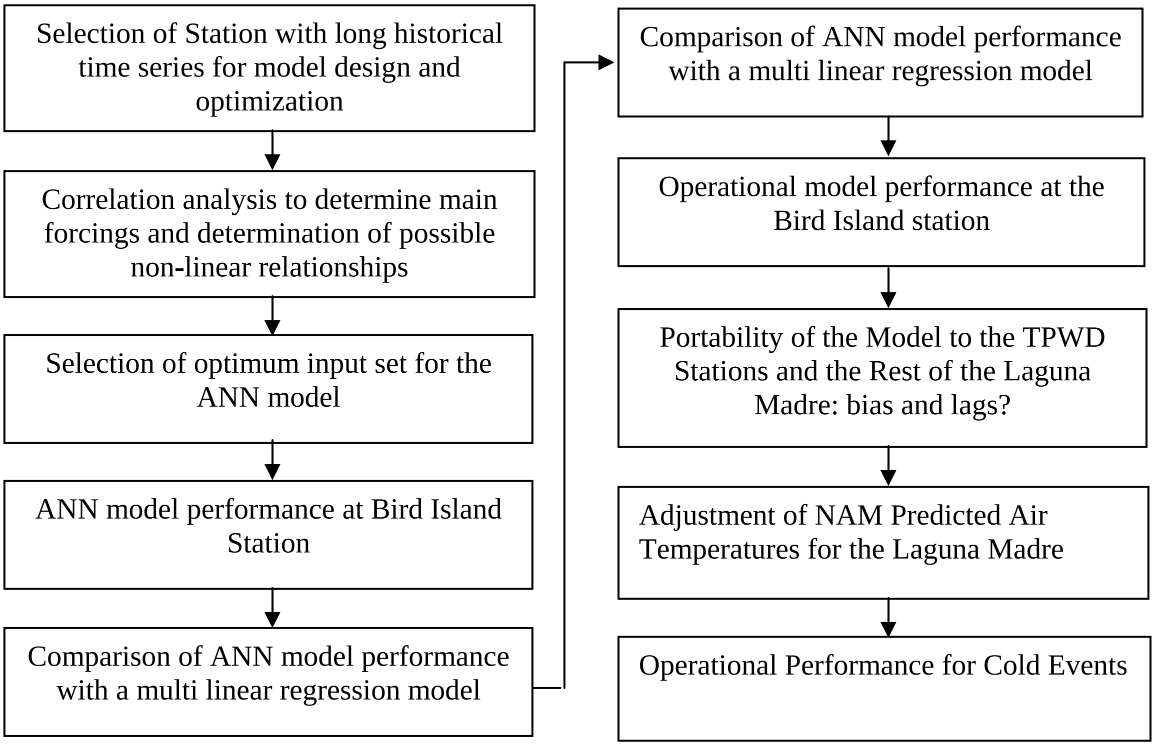

Figure 4. Schematic of the overall modeling approach for the study.

(tansig/purelin). All other possible combinations of transfer functions were also tested with the (tansig/purelin) model providing similar or better performance. The ANN models were developed, trained, and tested within the Matlab R2006b computational environment, utilizing the Neural Network Toolbox (The MathWorks, Inc., 2006). All ANN models were trained using the Levenberg-Marquardt algorithm.

The model training/testing was conducted with particular attention to cold water events. The presence of a variety of cold events led to the selection of 1996 as the main training set. 1996 saw six cold water events ranging from 2 to 110 hours. A full year was selected to the training data set for the model to include a sufficient amount of data for the training and to include all seasonal patterns. 1997 was another possibility but a significant amount of missing measurements during the cold water event of 1997, which resulted in a significant fish kill, ruled out that year for both training and testing. We selected three test years: 1995 with two cold water events (60 and 63 hrs), 2000 with four events (1, 3, 3, and 39 hrs), and 2001 with three events (3, 10, and 87 hrs). The optimized inputs to the neural networks consist of time series of previous water and air temperature measurements at Bird Island, water temperature measurements at Bob Hall Pier, and forecasted air temperature at Bird Island. A schematic of the neural network model is presented in Figure 5. The model functions as follows: first each element of the input set is multiplied by a weight (determined by the training procedure), all weighted inputs are then summed and transformed by the first neuron, the result is multiplied by another weight and finally transformed by the second neuron. The result is the forecasted water temperature.

The implemented real time model uses National Centers for Environmental Predictions (NCEP) air temperature predictions transmitted 4 times a day by the National Weather Service. However the model had to be initially calibrated using measurements as forecasts to have sufficient data and cases were available for the calibration (perfect prog methodology, see Wilks 2006). Results will are presented in the following section with both types of predictions. The atmospheric models used by NCEP vary periodically including during our test period. We used predictions from two models, the NCEP MesoEta model from 2004 to June 2006 and the NCEP NAM-WRF model after June 2006 (more information can be found in the full report). The portability of the model from the Bird Island station to the project station was tested by comparing temperature records and checking for possible lags. Figure 6 & 7 show that the temperature is mostly homogeneous for this part of the Laguna Madre and that water temperature predictions computed for the Bird Island station are valid for the project stations. A more detailed description of the project procedures, particularly the analysis supporting the model development can be found in the more extensive report (same title) submitted to Texas Parks and Wildlife concurrently with this report.

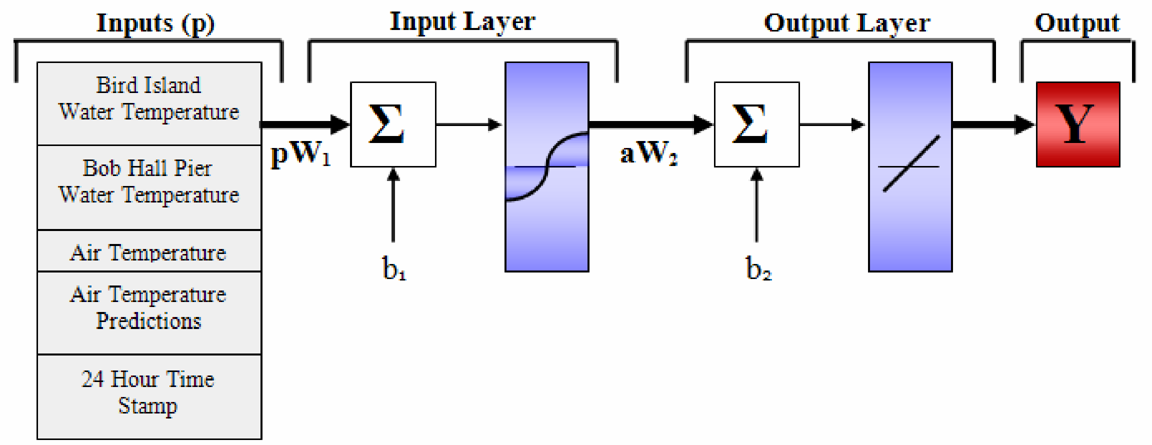

Figure 5. Schematic of ANN model. Tansig transfer function for input layer and a purelin transfer function for the output layer. $b_{1,2}$ are the biases and $\mathbf{W}_{1,2}$ are weight matrices for the respective layers.

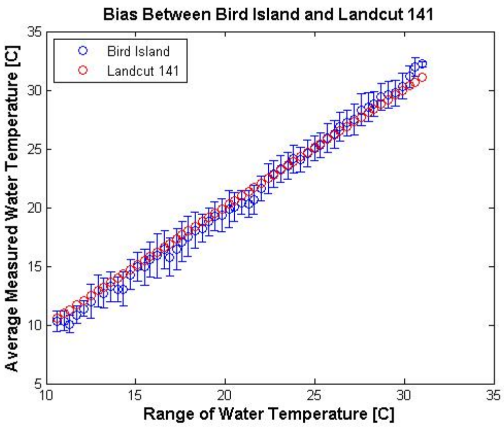

Figure 6. Measurement Biases Between Bird Island and Landcut 141. Error bars represent standard deviation.

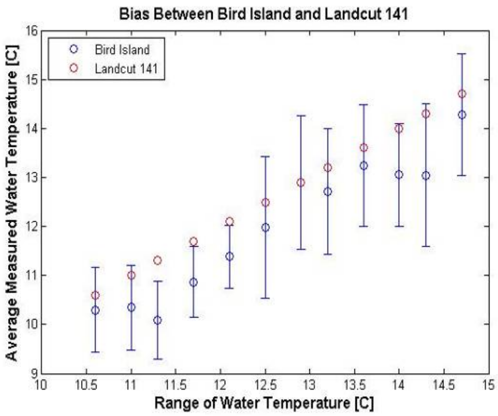

Figure 7. Measurement Biases During Cold Events Between Bird Island and Landcut 141. Error bars represent standard deviation.

IV. & V. Results & Analysis:

Temperature gradients were monitored hourly at both project stations, the Rincon station and the Land Cut station at 3’, 6’, 9’ and 12’ within the water column. Monitoring started respectively on February 27, 2006 and December 13, 2005. The Overall temperature measurements for both stations show higher temperatures in the summers in the 25°C to 34°C range from about mid May to mid October. During the rest of the year the temperature profiles are dominated by sharp and large temperature decreases created by the passage of cold fronts followed by more progressive temperature increases between frontal passages. The general tendency is for the low water temperatures reached to progressively decrease during the fall and first portion of the winter months and increase during the spring with the exact temperature dynamic depending on the intensity and number of cold fronts. The sharpest temperature drop during the project was observed in January 2007 with water temperatures decreasing from 22.5°C at 7:00 PM on January 15 down to 4.6°C on January 18 at 7:00 AM or about 18°C in 60 hours.

Throughout the study period the water temperatures were found to be mostly homogenous, i.e. temperatures within a 0.5°C range throughout the water column. Figure 8 illustrate the lack of thermal gradient at the Rincon station for more than a year (May 06 – August 07). A small moderating effect at the bottom of the channel, i.e. for the 12’ sensor, was observed during sharp temperature rises. Bottom temperatures during these events stayed cooler by 1°C to 2°C up to 5°C but the temperature gradients always rapidly disappeared within 8 hours or less. This moderating effect at the bottom of the Laguna Madre was however not observed during the sharp temperature decreases associated with frontal passages. The results of this study indicate that the temparture of the water column remains homogeneous during cold water events. To rule out the possibility that marine life seeks out warmer water during cold events, future monitoring could include temperature measurements in the muddy bottom of the Laguna Madre. Temperatures in shallow waters could also be monitored to investigate if significantly lower temperatures are reached at such locations. Comparing temperature records at both project stations (Figure 9) did not show substantial differences in temperatures. However while the data quality was excellent at the Rincon station the Landcut station encountered problems. As discussed in the full report the authors do not think that these problems affect the assessment of a homogenous water temperature for the study area. Comparison with other stations in the Laguna Madre also indicate a mostly homogeneous temperature distribution with some variability observed in the deeper waters of Corpus Christi Bay northward, the Brownsville ship channel southward, and at the Mansfield station which is linked to the Gulf of Mexico by a smaller ship channel.

The performance of the predictive water temperature model was computed using the perfect prog approach for several years with yearly average absolute error ranging from about 0.3°C for 3 hour predictions to about 0.7°C for 12 hour predictions, to about 1.0°C for 24 hour predictions and 1.7°C for 24 hour predictions. Year to year variability increased from up to 0.2°C for 3 hour predictions to up to 0.6°C, 0.14°C and 0.23°C for respectively 12 hour, 24 hour and 48 hour predictions. Cold water performance was analyzed for four events between 2003 and 2007 during which cold water temperature reached 8°C or below. The performance during these events was computed using past WRF-NAM predictions, i.e. operational forecasts very similar to the ones used in the live model. During the cold events the mean average absolute error was lower than 1°C for all predictions increasing from 0.1°C for 3 hour predictions to 0.9°C for the longer prediction times. The performance of the model during the December 21 – December 29, 2004 cold front passage is illustrated in figure 10 for 6, 12, 24 and 48 hour predictions. While the number of cold events with WFR-NAM predictions available is still small a mean average absolute error of 1°C is likely a good estimate of the average performance of the model for cold events with most of the errors within roughly a 2.5°C and larger errors possible but infrequent. The cold event performance was homogeneous across the

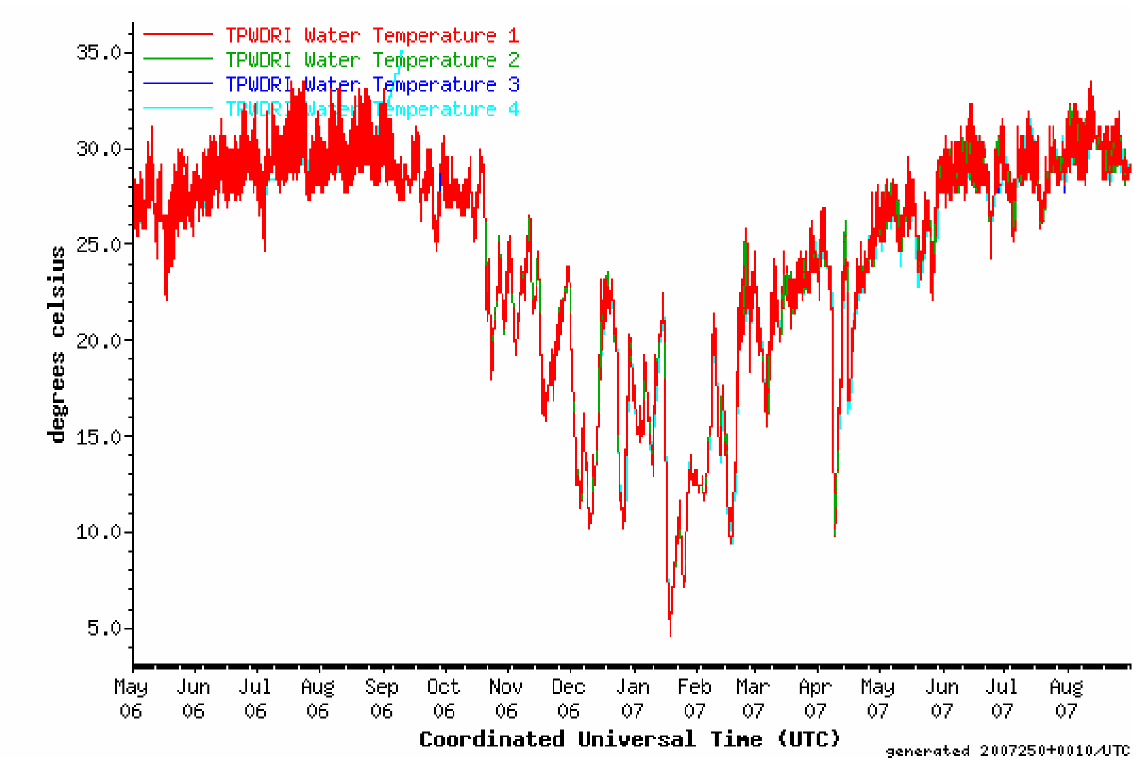

Figure 8. Water temperature measurements (3-hr frequency) for the 4 water temperature sensors at the TPWD Rincon station for the period of May 2006 to August 2007.

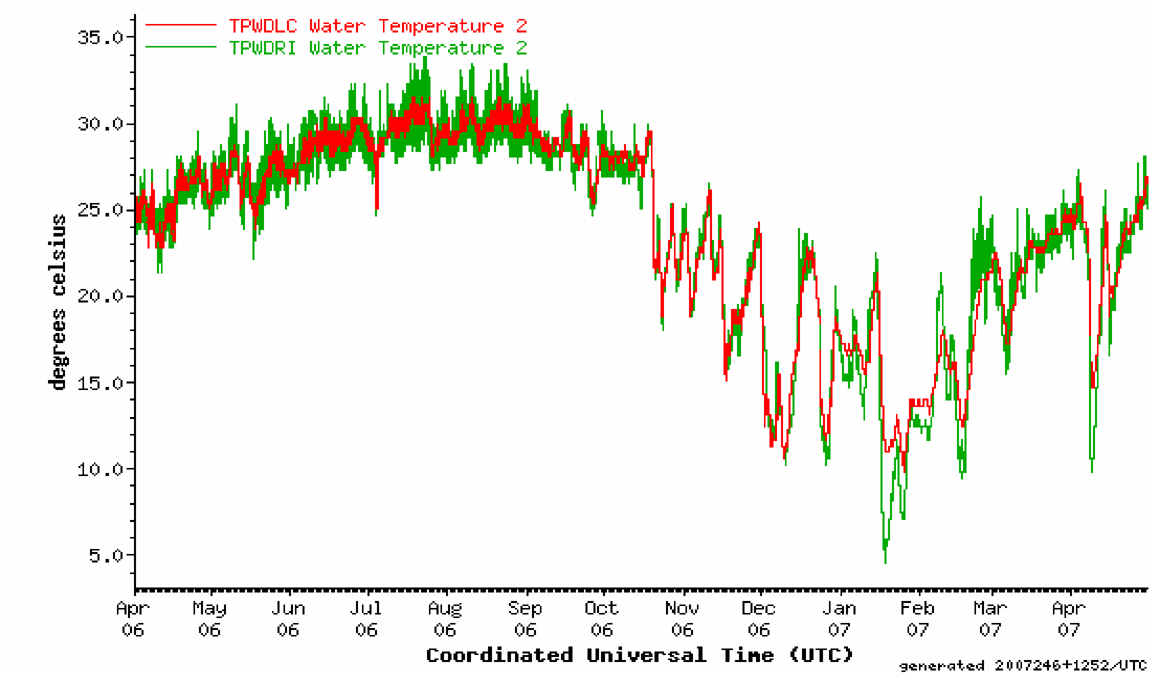

Figure 9. Comparison of water temperature measurements for sensors #2 at the Rincon (green) and Land Cut (red) stations for April 2006 to April 2007.

temperature range with variability and performance dominated by the accuracy of the WRF-NAM atmospheric predictions, i.e. the performance of the model will mostly depend on how well the atmospheric models capture the future dynamic of the cold fronts.

The performance of the model for cold water event was also evaluated based on its accuracy to detect an event (see Table 2). For these computations a cold event was defined similarly to the rest of the study as an event during which the water temperatures are predicted and/or measured below 7.2°C. The results are based on test years 1995, 2000 and 2001 (the ones with the largest number of cold events and including the greatest variability of events i.e. length of the event, temperature gradients during the event). Based on the available data if a cold event is not predicted by the model, the chances of such event taking place are virtually nil. Once an event is predicted, the chances that the event will indeed take place varies depending on the extent of the forecast from 90% for 3 hour predictions to 85%, 83% and 64% for 12, 24 and 40 hour predictions. If an event is not observed the chances that one was predicted are virtually nil and if a cold water event takes place there is a 70% to 80% chance that the event was indeed predicted.

The operational model was implemented as part of the DNR/TCOON website and can be consulted at the url: http://lighthouse.tamucc.edu/Forecasts/WaterLevelForecasts. Figure 11 illustrates the web display of the model predictions. The predictions are computed with the latest data available at the time of each request for a prediction graph. Measurements are updated up to a frequency of 6 minutes. Atmospheric predictions are updated every 6 hours and are provided typically with a delay of 3:35 hours after the nominal time of the prediction. Clicking the prediction graph leads to a more complex panel which includes graphs of recent past performance (see example in Figure 12 for a 24 hour performance of the same cold front) and comparison between predicted and measured air temperatures.

Figure 10. Comparison of Measured and Predicted water temperatures for the December 21 – December 29, 2004 cold front passage using both the perfect prog air temperature predictions (left) and MESO2 predictions (right). The predictions are for 6, 12, 24 and 48 hours.

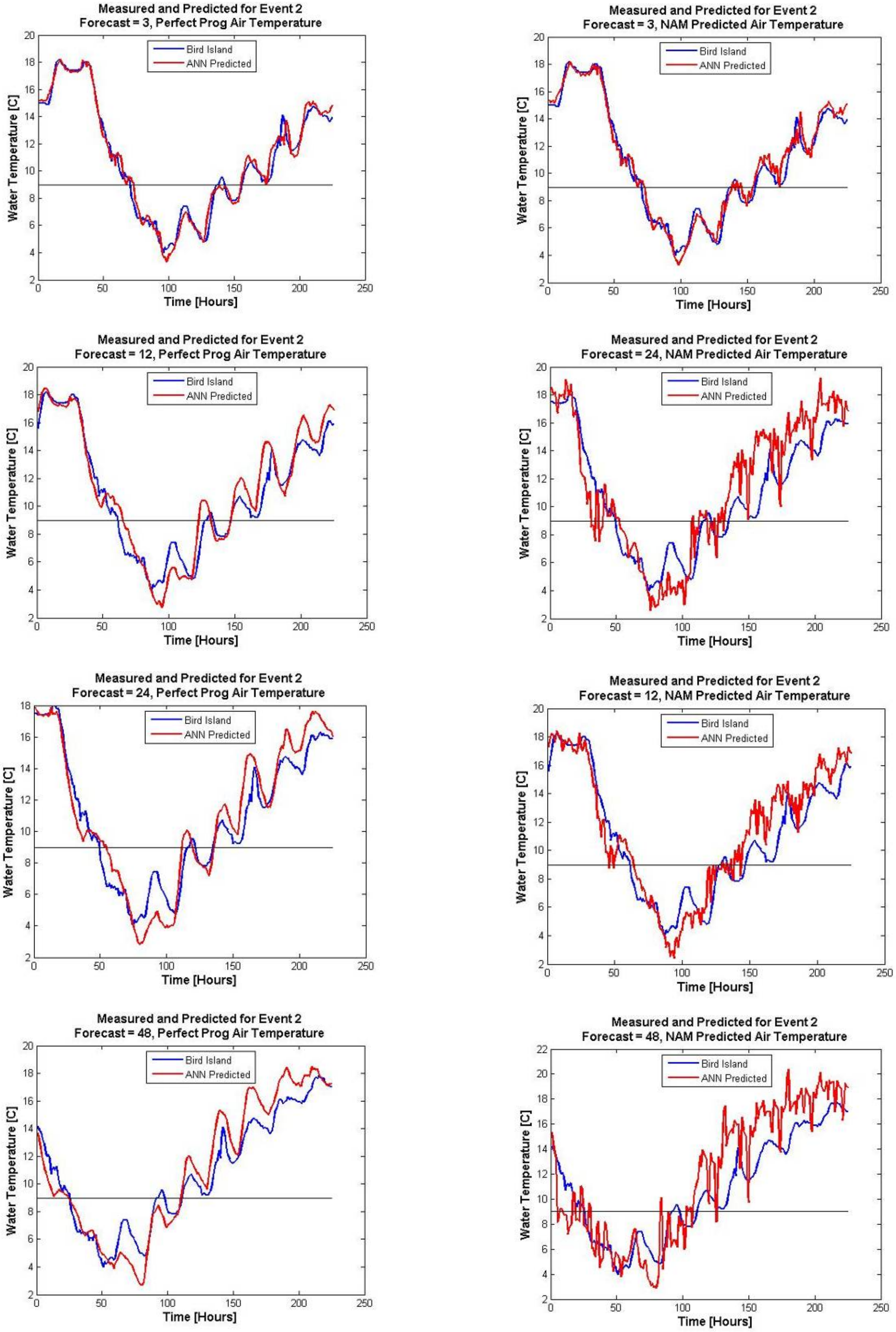

Table 2. Operational cases considered and related event probabilities.

Model Performance when a Cold Event is Predicted

Forecasts:	3 hrs	12 hrs	24 hrs	48 hrs
Probability that the event will indeed occur	0.90	0.85	0.83	0.64
Probability that the event will not occur	0.10	0.15	0.17	0.36

Model Performance when a Cold Event is not Predicted

Forecasts:	3 hrs	12 hrs	24 hrs	48 hrs
Probability the event will indeed not occur	0.998	0.997	0.998	0.998
Probability that the event will occur	0.002	0.003	0.002	0.002

Model Performance when a Cold Event is Observed

Forecasts:	3 hrs	12 hrs	24 hrs	48 hrs
Probability that the event was predicted	0.79	0.69	0.74	0.72
Probability that the event was not predicted	0.21	0.31	0.26	0.28

Model Performance when a Cold Event is not Observed

Forecasts:	3 hrs	12 hrs	24 hrs	48 hrs
Probability that the event was not be predicted	0.999	0.999	0.999	0.997
Probability that the event was predicted	0.001	0.001	0.001	0.003

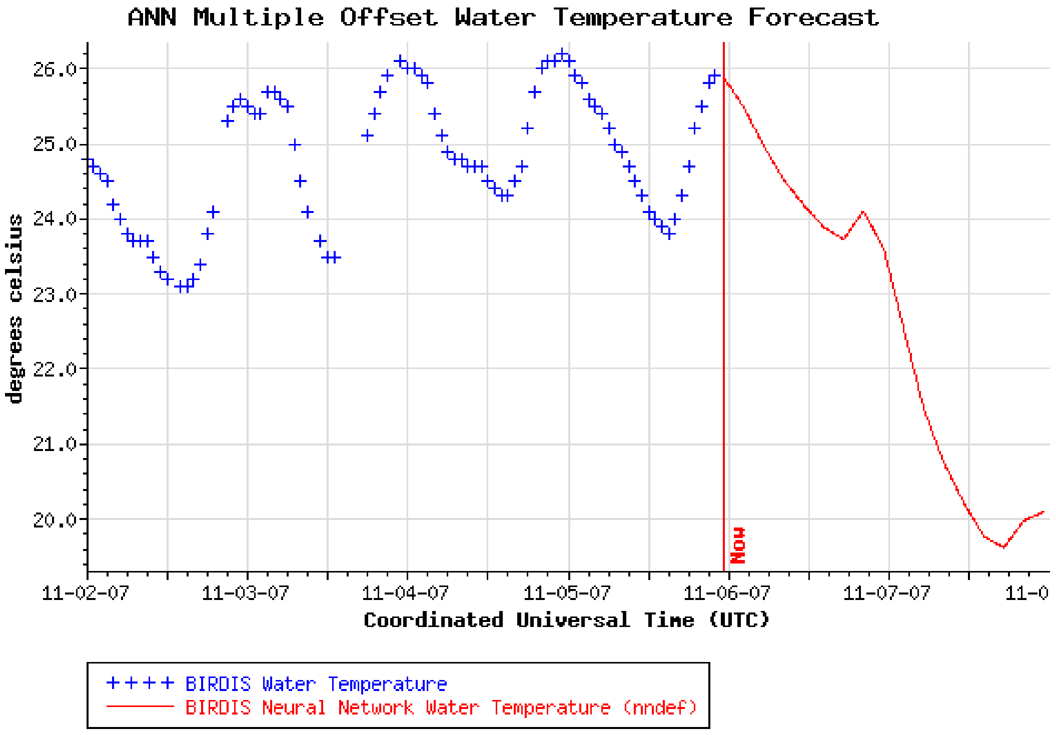

Figure 11. Web layout for the water temperature predictions. The graph presents the water temperature predictions ahead of the passage of the November 6, 2007 cold front.

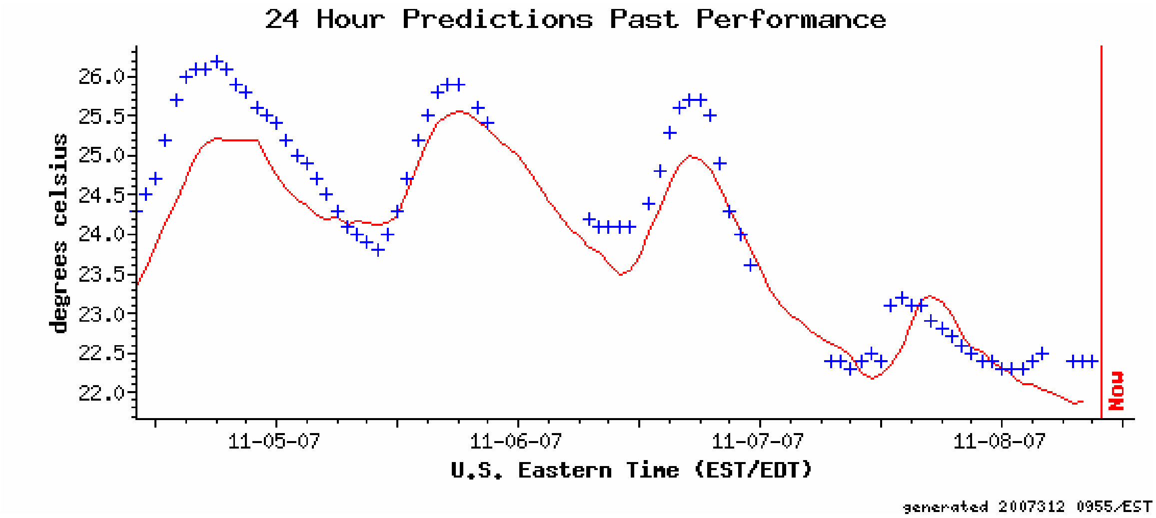

Figure 12. Web layout for the 24 hour performance of the water temperature prediction model. The graph presents the water temperature predictions after the passage of the November 6, 2007 cold front and was copied from the website 2 days and 9 hours after the graph presented in Figure 11.

V. Recommendations:

While good data sets were collected during the project continuous monitoring of the water temperature profiles at the project locations is highly desirable. The monitoring will be particularly useful to capture a larger number and broader range of cold water events. These additional events will be helpful to better define the performance of the model during such conditions and to confirm the absence of a vertical temperature gradient in a broader range of conditions. Other recommendations include adding other monitoring locations south of the present project stations, in shallower waters and/or in the muddy Laguna Madre. The addition of monitoring locations should be coordinated with other projects/agencies to minimize installation and maintenance cost. Modeling wise the use of other machine learning based techniques such as random forest modeling could prove helpful to improve the predictions specifically during cold events.

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SWG/LIP Administrator

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